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SCIENTIFIC REPORT

May 1978

BIOLOGICAL CHARACTERIZATION OF DEEP FLOW
REVERSALS IN THE STRAITS OF FLORIDA

by
Jeanne C. Stepien

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JUN 21 1978

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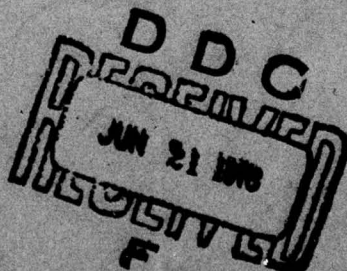
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May 1978   250 p.

BIOLOGICAL CHARACTERIZATION OF DEEP FLOW REVERSALS
IN THE STRAITS OF FLORIDA.

by

Jeanne C. Stepien

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JUN 21 1978
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A dissertation submitted in partial fulfillment of
the requirements for the degree of
Doctor of Philosophy

Doctoral thesis,

Submitted to

Rickenbacker Causeway
Miami, Florida 33149

William W. Hay
Dean

STEPIEN, JEANNE CRUISE (Ph.D, Biology and Living Resources)

Biological characterization of deep flow reversals in the
Straits of Florida. (May, 1978).
Abstract of a doctoral dissertation at the University of
Miami.
Dissertation supervised by Dr. Harding B. Michel.

The occurrence of chaetognath, euthecosome, and euphau-
siid species in relation to deep flow reversals in the
Florida Straits off Miami was examined during four, 3- to
10-day periods in 1972-1974. Simultaneous zooplankton col-
lections and current profiles were made at 6-hr intervals
while anchored in 650-800 m at a station 15 miles east of
Miami. The sampling depth was 600-750 m and the duration of
fishing 1-1½ hrs.

Time-depth contour plots of the u- and v-components of
velocity and temperature show variations in the deep current
similar to those found by previous investigators. Deep flow
reversals of varying intensity occurred at several-day inter-
vals. When the v-component was directed toward the north,
the u-component was easterly, and the thermal structure,
particularly in the region of the 10°C - 15°C isotherms, was
flat and broad. When the v-component was oriented toward
the south, cross-stream flow was westerly, and the 10°C -
15°C isotherms were noticeably steepened.

Twenty species of Chaetognatha, 14 species, 1 subspe-
cies, and 9 formae of Euthecosomata, and 15 species of

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Euphausiacea were identified in the deep samples. The observed distribution patterns of these species were evaluated in terms of the known horizontal and vertical ranges of each species and compared with the simultaneously collected physical data. Combinations of epipelagic neritic and oceanic chaetognath species with meso- and meso-bathypelagic forms and the presence of many euthecosome species during pulses of deep southwestward flow indicate a downward movement of shallow oceanic waters. These data, as well as previous studies on the vertical distribution of chaetognaths and euthecosomes in the Straits, support the hypothetical sub-geostrophic condition thought to occur in the Florida Current, i.e., downwelling along the lower edge of the thermal front roughly defined by the 10°C - 15°C isotherms by a positive u-component during northward flow. The relative proportions of epipelagic species found below 600 m and the presence of certain species, e.g., <u>Sagitta</u> <u>tenuis</u> and <u>Eukrohnia</u> <u>hamata</u> suggest that the deep water present in flow reversals consists of a mixture of coastal, shallow oceanic, and deep oceanic waters from both local and northern regions.

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ACKNOWLEDGMENTS

Many people have contributed to this study and to all, I express my thanks. In particular, I wish to thank Dr. Harding B. Michel, chairman of my dissertation committee. Her guidance, encouragement, and criticism throughout all aspects of this study have been invaluable and are deeply appreciated. I would like to thank the members of my committee, Drs. Eugene F. Corcoran, Donald P. de Sylva, Walter O. Düing, and Michael R. Reeve for their critical reveiw of the manuscript and helpful discussions in the course of this study. Special thanks are given to Dr. Walter O. Düing for his aid in interpreting the physical data and to Dr. Hilary B. Moore for critically reviewing the manuscript.

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Finally, I would like to thank my husband, Walter, for his support and encouragement throughout this study.

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Coral Gables, Florida   Jeanne C. Stepien

May, 1978

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INTRODUCTION

Deep current reversals in the Straits of Florida have
been the subject of speculation and study since the late
nineteenth century when Pillsbury (1891) made his classic
series of current observations aboard the BLAKE. He meas-
ured temperature and current at various depths along sev-
eral cross-sections in the Florida Straits and, on the
basis of his observations between Fowey Rock and Bimini,
postulated the periodic presence of a southward-flowing
bottom current in all parts of the Straits except the
extreme eastern section. Since Pillsbury's work, support
for the existence of transient deep southward flow has come
from physical oceanographers and geologists. Wüst (1924),
applying the dynamic method to temperature and salinity ob-
servations made between Fowey Rock and Bimini, found evi-
dence of deep flow to the south. Hurley and Fink (1963)
obtained photographs of ripple marks on the east-central
floor of the Straits formed by a current flowing south at
an estimated 10-30 cm/sec. Visual observations of sedi-
mentary structures and current measurements made by Neumann
and Ball (1970) from the submersible ALUMINAUT indicated a
southward-flowing bottom current of approximately 5 cm/sec
in the region of the Miami Terrace Escarpment, and direct
measurements in the same area by the free-instrument tech-
nique (Richardson and Schmitz, 1965) also indicated a weak
southerly flow (Richardson, et al., 1969). The periodic

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occurrence of deep southward flow on the western side of the Straits has been confirmed by Düing and Johnson (1971, 1972) and Düing (1973, 1975). They used a profiling current meter to obtain high resolution profiles of the vertical structure of the Florida Current and recorded a maximum of 87 cm/sec for southward flow in the deepest part of the Straits off Miami. Their results indicated that changes in current direction from north to south typically occur every 4 or 5 days and are accompanied by a 180° shift of the cross-stream component from east to west, fluctuations in volume transport, and a steepening of the isotherms (Düing, 1975). Recent studies by Düing et al. (1977) and Schott and Düing (1976) suggest that these fluctuations are caused by barotropic continental shelf waves.

The purpose of this study was to examine the deep zooplankton in relation to flow reversals in the Straits of Florida. Zooplankton may be used to indicate changing hydrographic conditions because water masses and currents are defined by distinct physical and chemical properties and thus are characterized by distinctive faunas. Water masses are continually being renewed by mixing with water from other systems, each with its own physical, chemical, and biological identities. The mixed waters retain the characteristics of the main water mass. However, if the planktonic fauna of both the original water mass and the system which has been entrained are well known, it is possible to follow the movement of the entrained parcel of water despite

the loss of its original physical-chemical identity through mixing. It is in such situations that the use of "indicator species" can serve to check the results of physical-chemical studies or provide information, not otherwise obtainable, on the circulation and origin of water masses and current systems (Johnson and Brinton, 1963). The latter represents the most sophisticated use of indicator organisms. It was hoped that the zooplankton collected in the present study could provide additional information, not readily detected by oceanographic instrumentation now in use, on deep flow reversals in the Florida Current.

The Chaetognatha, Euphausiacea, and Euthecosomata were chosen for study. On the basis of extensive reviews by Alvariño (chaetognaths, 1965), Mauchline and Fisher (euphausiids, 1969), and van der Spoel (euthecosomes, 1967, 1976), it is clear that these organisms meet most of the criteria for the selection of indicator species (Sverdrup et al., 1942; Boltovskoy, 1965; Myers, 1968). The taxonomy and geographic range of species in each group are well defined and the life cycle and vertical migratory patterns of many have been described. The animals are of sufficient size to be handled easily in the laboratory, present no unusual problems in preservation, and are found in sufficient numbers to permit statistical analysis.

Each group has been successfully used in previous studies to define water masses, current systems, and mixing processes, as follows: chaetognaths (Russell, 1935, 1936,

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1939; Hida, 1957; Bieri, 1959; Pierce and Wass, 1962; Fager
and McGowan, 1963; Stone, 1969; Boltovskoy, 1975 a; Michel
et al., 1976), euphausiids (Brinton, 1962; Fager and McGowan,
1963; Johnson and Brinton, 1963; Ponomareva, 1963; Roger,
1974; Michel et al., 1976; Wiebe et al., 1976), and eutheco-
somes (Hida, 1957; McGowan, 1960; Fager and McGowan, 1963;
Chen and Bé, 1964; Myers, 1968; Chen and Hillman, 1970;
Austin, 1971; Boltovskoy, 1971, 1975 a; Haagensen, 1976).
In view of these investigations and the abundance of the
Chaetognatha, Euphausiacea, and Euthecosomata in the Straits
of Florida (Lewis, 1954; Owre, 1960; Wormelle, 1962), it
seemed logical to select these groups for study.

During four surveys at an anchored station 15 miles
east of Miami, samples of deep zooplankton were collected in
conjunction with simultaneous current profiling. The occur-
rence of chaetognath, euphausiid, and euthecosome species
was evaluated in terms of the north-south and cross-stream
components of velocity and temperature in an attempt to
further characterize the changing vertical structure of the
Florida Current.

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METHODS

Sampling Sites

During four periods in 1972-1974, collections of deep zooplankton were made in conjunction with simultaneous current profiling from the University of Miami's R/V COLUMBUS ISELIN, while it was anchored at a station in the Straits of Florida 15 miles east of Miami. The location of the stations and a cross-section along 25°38.5'N latitude are shown in Figs. 1 and 2. The sampling area was chosen on the basis of data from Project SYNOPS-71 (Synoptic Observations of Profiles in the Straits) which indicated that the most pronounced deep flow reversals occurred in the deepest part of the Straits off Miami (Düing, 1975). The dates, position, and depth of each station are summarized in Table 1. The depths are average values. At times, deviations of several hundred meters occurred in the ship's position due to changes in the cross-stream or east-west component. This accounts for the apparent discrepancy in depths between CI-7309 and CI-7317. Since the vessel was variously anchored in a depression (Fig. 2), displacement to the east or west resulted in different average depths.

Sampling Procedure

The simultaneous collection of physical and biological data in this study required the development and use of a new sampling technique which has been described by Low, Stepien

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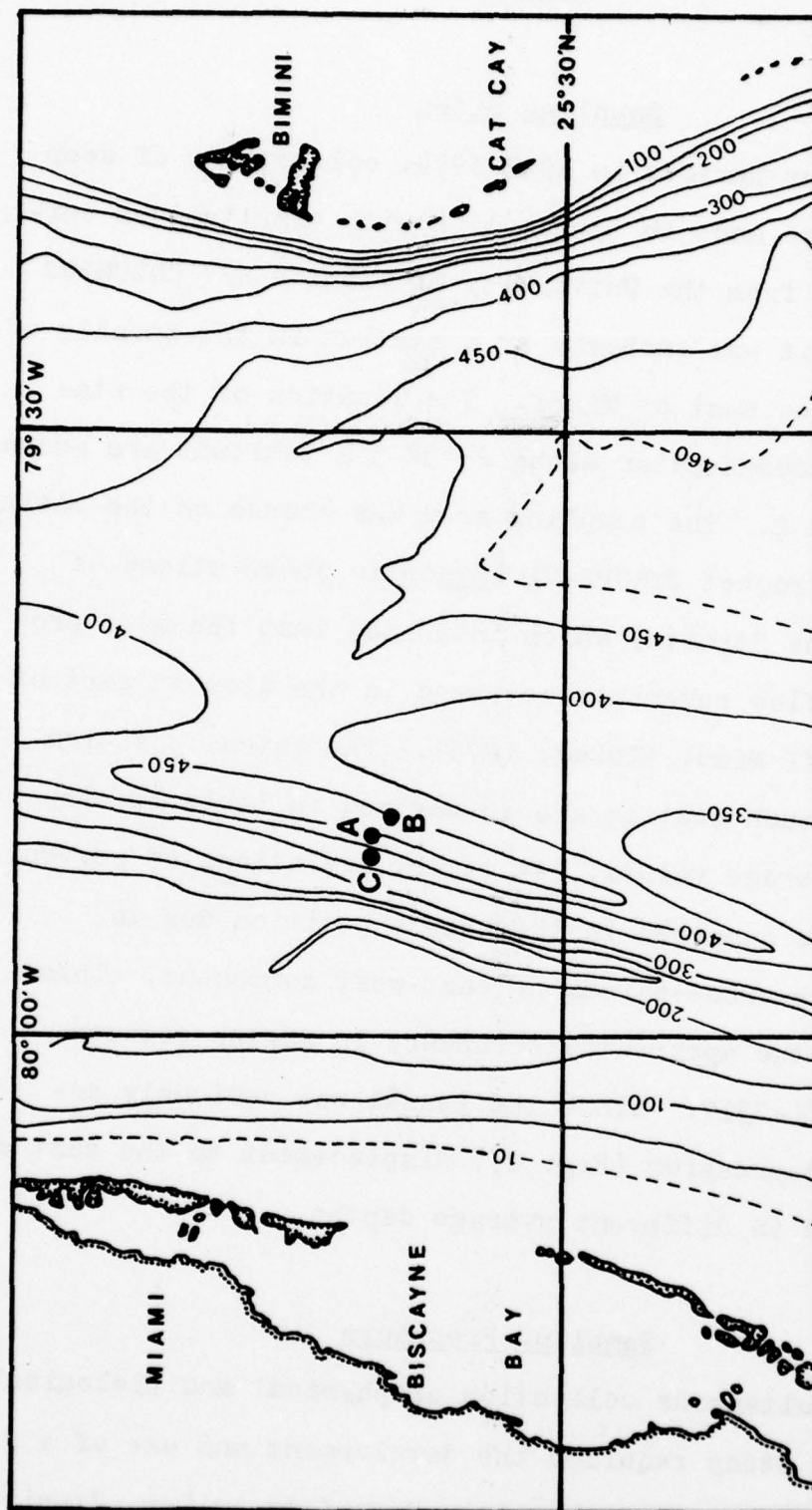
Figure 1

Positions of stations. A: CI-7206. B: CI-7309 and CI-7317.
C: CI-7401.

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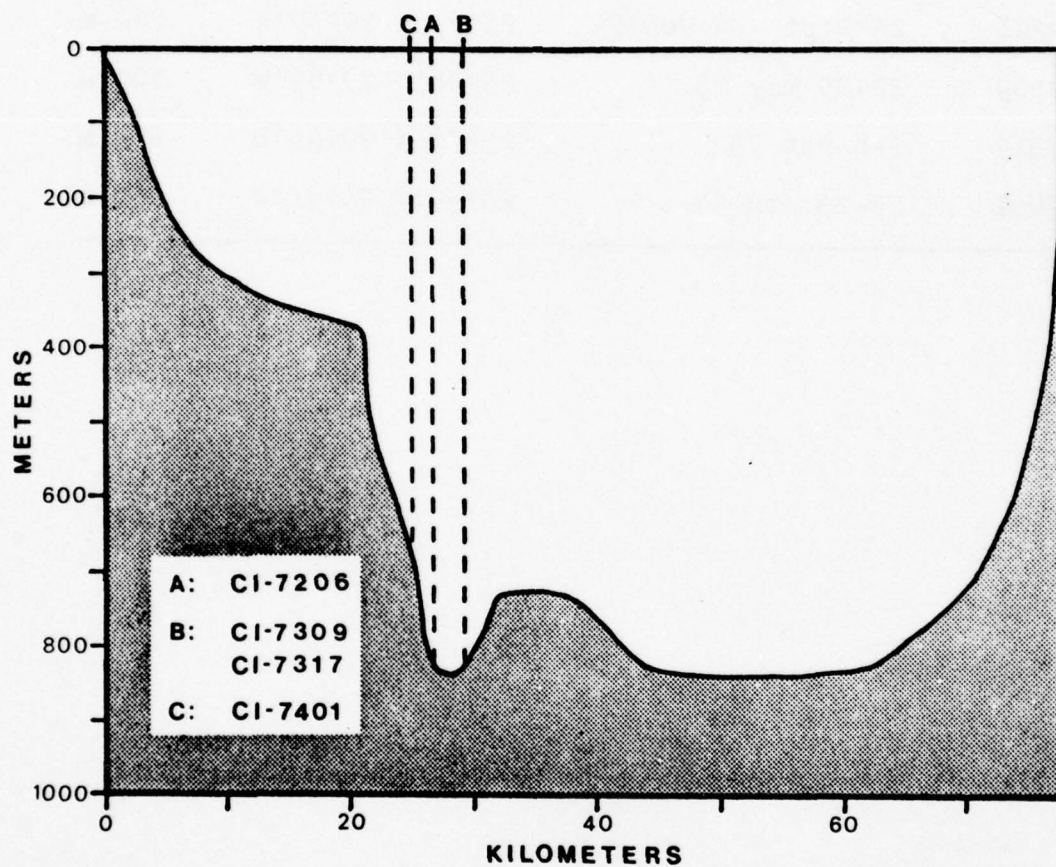
Figure 2

Corresponding bottom profile for stations in Figure 1.

Table 1

Dates, positions, and average depths for each station.

Cruise	Date	Position	Depth
CI-7206	25 Sept - 4 Oct 72	25°39'N 79°50'W	700 m
CI-7309	22-25 May 73	25°38'N 79°49'W	700 m
CI-7317	5-8 Oct 73	25°38'N 79°49'W	800 m
CI-7401	19-25 Jan 74	25°39'N 79°51'W	650 m

and Michel (1975). Since comprehension of the sampling pro-
cedure is basic to understanding the results, the method
will be briefly restated, beginning with a consideration of
the equipment used to collect both physical and biological
data.

A profiling current meter (PCM) was used to record
changes in vertical structure. The PCM, described by Düing
and Johnson (1972), consists of a self-contained Aanderaa
current meter which samples current speed and direction,
pressure, temperature, conductivity, and battery reference
as a function of time. It is mounted in a cylindrical poly-
vinyl chloride hull, which is attached to hydrographic wire
by a snatch block and ballasted to remain horizontally
trimmed during free descent. As it descends, the PCM samples
a variable ($|v|$, p, t, ϕ, reference, blank) approximately
every 5 sec and thus records each of the six variables every
30 sec. In the present study, the channels were sampled at
27-sec intervals which corresponds to vertical resolution of
about 5 m in the upper layers and about 2 m in the lower
layers. Because the conductivity sensor in the current meter
was not functioning during the four sampling periods, water
samples for salinity determination were collected with a
1.7-1 Niskin bottle equipped with reversing thermometers
and positioned directly below the net assembly.

The plankton samples were collected with a modified
Discovery net which was opened hydrostatically and closed
mechanically at the desired depth. The net, equipped at the

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mouth with a Niskin digital flowmeter (Model #2030), was approximately 3.5 m long with a diameter of 75 cm at the mouth and 10 cm at the cod end. It was constructed of graded mesh with mesh sizes, from mouth to cod end, of 3.2 mm, 1.6 mm and 100 um (Owre and Low, 1969). A graded mesh net was chosen for several reasons. Previous investigators have used this type of net to study the chaetognaths (Owre, 1960), euphausiids (Lewis, 1954), and euthecosomes (Wormelle, 1962) in the Florida Current off Miami. Its use here thus permitted comparisons between earlier results and those obtained in the present study. In addition, the modified Discovery net collects a wide range of organisms in good condition (Owre and Foyo, 1972).

In the sampling procedure, the PCM descended the wire freely while the net fished near bottom. The simultaneous use of the PCM and net precluded the use of messengers dropped from the surface for opening and closing the net. A mechanism employing a cylinder and piston principle and operated by hydrostatic pressure was therefore designed to release the rolled net at the desired fishing depth. A simple, single release mechanism, actuated by the weight of the descending profiler, was used to close the net. These mechanisms are described in detail by Low, Stepien and Michel (1975).

The method of simultaneous plankton sampling and current profiling used in this study required that the vessel be anchored. A 300-kg lead weight was suspended from the hydro-

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wire to keep it as nearly vertical as possible. A 1.7-1 Niskin bottle was then clamped to the wire approximately 10 m above the weight and a Benthos Time-Depth Recorder above the bottle. The wire was lowered 2 m and the sampling unit, including the single release, hydrostatic release, and the rolled net, was secured to the wire (Figs. 3 and 4A). The net was lowered approximately 20 m and the PCM, already attached to the hydrowire, was lowered to the surface where it remained until its release. Payout of wire was resumed and the net was slowly lowered to the desired depth where the hydrostatic release was actuated, freeing the net to fish and releasing the first messenger. The messenger released the snapper block, which secured the net frame to the wire, and struck the clamp of the Time-Depth Recorder (Fig. 4B), causing the stylus of the Recorder to mark the chart, thus indicating when and at what depth the net opened. Meanwhile, the PCM was released from the surface (Fig. 4B). When its profile of the water column was complete, it settled on and actuated the single release mechanism, freeing the bridle and releasing the remaining two messengers. The net was then closed by the choke line as the second messenger struck the Time-Depth Recorder, marking the end of fishing, and the third closed the Niskin bottle, causing the thermometers to reverse (Fig. 4C). All equipment was then returned to the surface where the zooplankton sample was removed from the net bucket and fixed in 10% formalin buffered by adding hexamethylene tetramine to saturation.
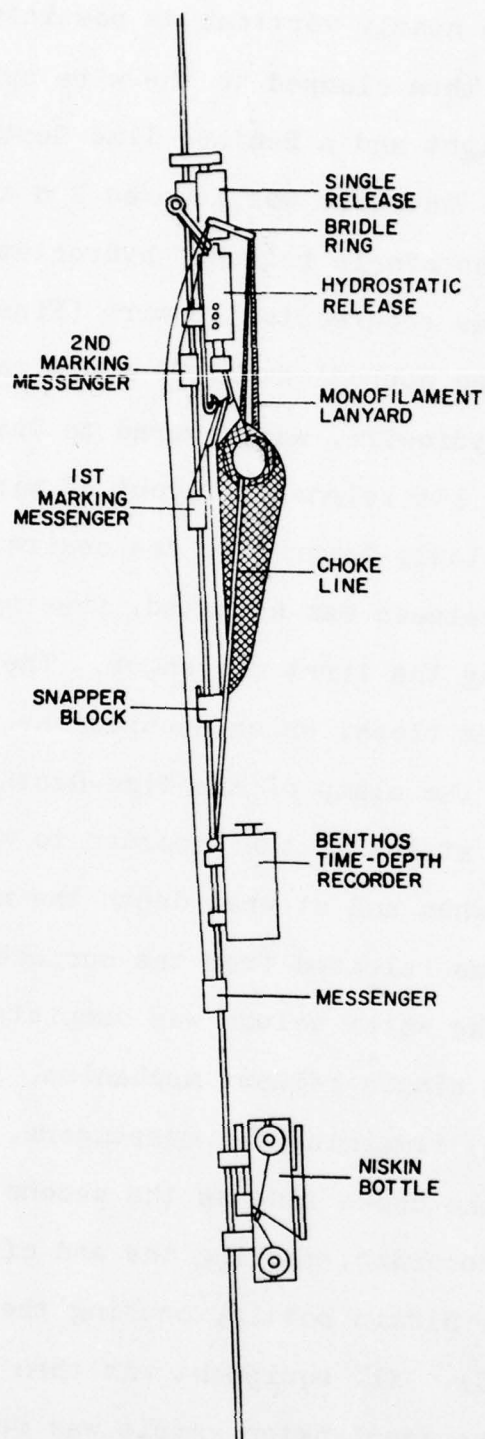
Figure 3

Plankton sampling unit ready for lowering (modified from Low, Stepien and Michel, 1975).

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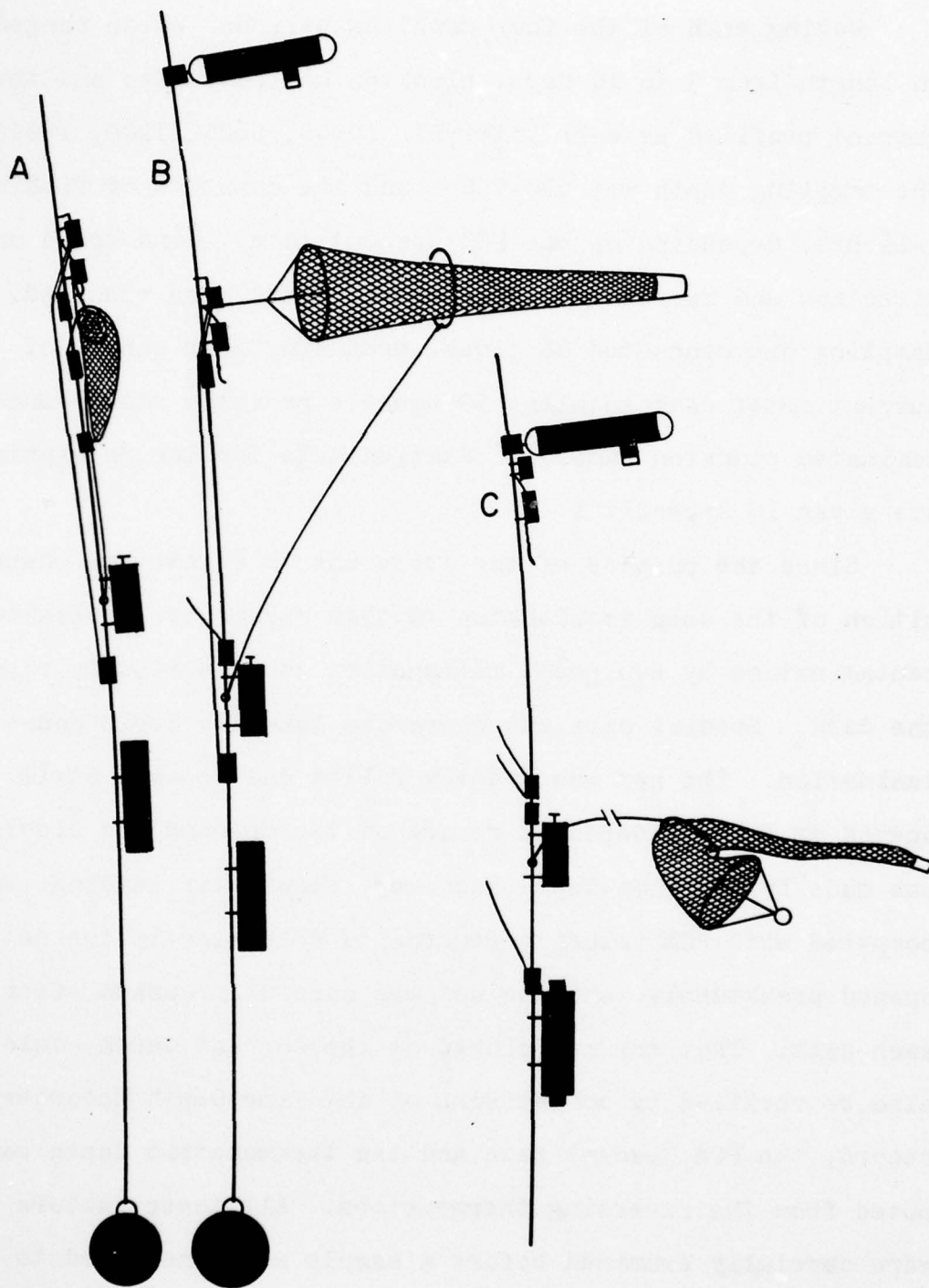
Figure 4

Plankton net and PCM in operation: A. Rolled net ready for
lowering. B. Net open and fishing, PCM descending. C. Pro-
file complete, net and Niskin bottle closed and ready to be
raised (modified from Low, Stepien and Michel, 1975).

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During each of the four sampling periods, which ranged in length from 3 to 10 days, plankton was collected and the current profiled at 6-hr intervals (0000, 0600, 1200, 1800). The sampling depth was 600-750 m and the duration of fishing 1-1½ hrs, depending on the PCM descent rate. Wind speed and direction and surface current velocity were also recorded. Sampling was conducted 86 times, producing four series of current meter data totaling 79 usuable profiles and 57 uncontaminated plankton samples. Station data for the 86 stations are given in Appendix I.

Since the purpose of the study was to relate the composition of the deep zooplankton to flow reversals, biological contamination by equipment malfunction could seriously bias the data. Special care was therefore taken to avoid contamination. The net was tightly rolled and secured until it opened at fishing depth; a record of the opening and closing was made by the Time-Depth Recorder; flow meter readings were compared with PCM velocity records to determine if the net opened prematurely, and the net was carefully washed after each cast. That the net closed at the correct depth could also be verified by comparisons of the Time-Depth Recorder record, the PCM descent rate and the thermometric depth computed from the reversing thermometers. All these factors were carefully examined before a sample was considered to be uncontaminated. No samples suspected of contamination were analyzed.

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Data Analysis

Physical Data:

The Aanderaa current meter records data on $\frac{1}{4}$-inch magnetic tape. These data were converted to computer tape format and processed according to Düing (1973). This program identified parameters, built logical records or lines of data consisting of the reference number, temperature, depth, and current speed and direction, applied calibration values, and converted the data to physical units. Depth vs. sample number was then printed for all data. The printouts from the four series of PCM records were used as the basis for all further analyses of physical data.

The u- (east-west) and v- (north-south) components of velocity were computed for each observed current vector (Fig. 5). Positive values for the u- and v-components correspond to eastward and northward flow. Negative values represent flow to the west and south. Time-depth contour plots of the u- and v-components and temperature from 300 m to the bottom were drawn for each set of data. These plots are useful in representing large quantities of data. For example, the contour plot of the v-component for CI-7206 from 300 m to the bottom (Fig. 9) is based on a matrix of approximately 1200 data points. A depth of 300 m was chosen as the upper limit for the plots because the study was concerned only with deep reversals. Since deep flow reversals are accompanied by a steepening of the isotherms which is most noticeable in the region of the 10°C and 15°C isotherms,

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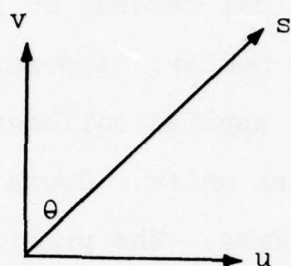
$$u = s \sin \theta$$
$$v = s \cos \theta$$

where:

u = east-west component of velocity

v = north-south component of velocity

s = current speed in cm/sec as measured
by the Aanderaa current meter

θ = current direction as measured by the
Aanderaa current meter where 0° is
due north and 180° is due south

Figure 5

Calculation of the u- and v-components from the Aanderaa current meter data.

contours of these temperatures were also plotted for each
data set.

Temperatures and thermometric depths were calculated
from the reversing thermometer data. An induction salino-
meter was used to determine salinity. Density values (σ_t)
were computed from the temperature and salinity data and
plotted as a function of time and depth. Wind speed vs.
time was also examined since atmospheric forcing is thought
to play a role in deep flow reversals.

Biological Data:

For each plankton collection, the depth and duration of
fishing were determined from the Time-Depth Recorder chart
and the volume in m^3 filtered by the net was calculated from
the flow meter readings according to the following formula:

$$\text{Volume filtered } (m^3) = .2675 \text{ x area of net x reading (revolutions).}$$

Fishing depths and volumes filtered are included in Appendix
I.

All chaetognaths, euphausiids, and euthecosomes in the
samples were identified and counted. The major references
used to identify specimens are summarized in Table 2. A
review of the citations in Table 2 for the Chaetognatha and
Euphausiacea will demonstrate that the taxonomy of these
groups has been clearly defined. The classification scheme
outlined by these references has been adopted by all major
workers in the field with the exception of Tokioka (1965,
Chaetognatha). The Euthecosomata are well-defined specifi-
cally. van der Spoel (1967, 1969 a; 1971 b), however, has

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Table 2

Major references used for identification of the
Chaetognatha, Euphausiacea, and Euthecosomata.

Chaetognatha	Fowler, 1905; Michael, 1911, 1919; Ritter-Záhony, 1911 a,b; Germain and Joubin, 1916; Thomson, 1947; Pierce, 1951; Fraser, 1952; David, 1955, 1958; Suárez-Caabro, 1955; Tokioka, 1955 a; Furnestin, 1957; Alvariño, 1962, 1967, 1969; Dallot and Ducret, 1969; Dallot, 1970; Owre, 1972, 1973, 1978.
Euphausiacea	Sars, 1885; Ortmann, 1893; Hansen, 1905, 1910, 1911, 1912; Ruud, 1936; Einarsson, 1942; Sheard, 1953; Boden, 1954; Boden, Johnson and Brinton, 1955; Mauchline and Fisher, 1969; James, 1970; Gopalakrishnan, 1975.
Euthecosomata	Fol, 1875; Tesch, 1904, 1913, 1946, 1947; Meisenheimer, 1905; Vayssière, 1915; Tokioka, 1955 b; Rampal, 1965, 1967; van der Spoel, 1967, 1968 a,b, 1969 a,b, 1970 a,b, 1971 a, 1972, 1974, 1976; Lalli and Wells, 1973; Panhorst and van der Spoel, 1974; Haagensen, 1976.

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stressed the importance of infraspecific levels and has introduced the term "forma" for infrasubspecific forms. This term is not used by all investigators. van der Spoel (1971 b) has stated that subspecies are limited in their distribution by oceanic provinces while formae are restricted to particular water masses. This would make infraspecific forms very useful as indicators of water masses and current systems, and thus all euthecosomes have been identified to subspecific and infrasubspecific levels whenever possible.

Individual species and total counts in a sample were expressed as numbers per 1000 m^3 and per cent numbers per 1000 m^3 of water filtered by the net. Since a graded mesh net was used, numbers per 1000 m^3 does not refer to standing stock but rather, is a measure of relative abundance. Data resulting from the identification and enumeration of species from each sample are listed in Appendix II. For the chaeto-gnaths and euphausiids, various stages of maturity are in-cluded in the numbers per 1000 m^3 recorded for each station. A separate category in the euphausiid tables has been made for immature specimens whose identities could not be deter-mined with certainty. The euthecosomes at each station are recorded as adults, juveniles, and totals for each species and forma. The adult and juvenile euthecosomes are listed separately because of the high percentage of juveniles present in the samples. Following Haagensen (1976), differ-entiation between adults and juveniles was based on size ranges as determined from historical data.

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An attempt was made to group the samples on the basis of species similarity. The method involved the calculation of a similarity index between each possible pair of samples. Portions of the derived matrix of similarity coefficients were subjected to cluster analysis and the resulting groups of samples represented diagramatically by cluster analysis plots.

Numerous methods for expressing the relative similarity or dissimilarity of two populations have been proposed (Sokal and Sneath, 1963; Sneath and Sokal, 1973; Clifford and Stephenson, 1975). Two of the more common ones are Sørensen's (1948) coefficient of similarity and Whittaker's (1952) percentage similarity index. Sørensen's index measures relative similarity in terms of species composition and is defined as follows:

$$S = \frac{2C}{A + B}$$

where A = the number of species in sample A, B = the number of species in sample B, and C = the number of species common to both. This index is dependent on sample size (Mountford, 1962) and tends to overvalue minor species to the neglect of differences in dominance and major species (Whittaker and Fairbanks, 1958). It has been used to express similarity between plankton samples by Boltovskoy (1975 b) and Geynrikh (1976). Whittaker's percentage similarity measures the relative similarity of the numerical composition in terms of species populations and is defined as:

$$PS = 1 - .5 \sum |a-b| = \sum \min (a,b)$$

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where a and b are the percentages of samples A and B which a given species represents. The index may be obtained simply by summing the smaller percentages of each species common to the two samples being compared. This measurement will generally result in the grouping of populations by dominants or major species but may overvalue the dominance of major species to the neglect of differences in the composition of the community as a whole (Whittaker and Fairbanks, 1958). When dealing with relatively small numbers of species, as is the case in this study, this analysis has been shown to produce better results than indices similar to Sørensen's (Whittaker and Fairbanks, 1958). It has been successfully used in plankton studies by Whittaker and Fairbanks (1958), Miller (1970), Wiebe (1970, 1971), Wiebe and D'Abramo (1972), Haury (1976 a,b), and Wiebe et al. (1976).

Whittaker and Fairbanks (1958) state that depending on conditions, it may be appropriate to use both indices. It seemed desirable to use both in this study. Thus, Sørensen's index was calculated to look closely at the minor species, while Whittaker's was computed to obtain natural groupings based on dominant species.

Species which occur infrequently are often excluded from data analysis in ecology. According to Clifford and Stephenson (1975), however, it might be desirable to retain them in a plankton study using indicator species. In this study, therefore, the infrequently occurring species were included in the similarity computations. Sørensen's similarity index

and Whittaker's percentage similarity index were calculated for the chaetognaths, euphausiids, and euthecosomes. The similarity values were subjected to cluster analysis (Sneath and Sokal, 1973; Clifford and Stephenson, 1975) in order to group the samples. The clustering techniques used were the single linkage and group average methods. Two methods were employed in order to test the usefulness of each technique. The single linkage method often shows excessive elongate growth or chaining which results in a loss of information (Sneath and Sokal, 1973). However, Jardine and Sibson (1971) on mathematical grounds have shown it to be superior to the group average method, which was designed to overcome the problems of chaining. The group average or unweighted pair-group method using arithmetic averages tends to accentuate distinct groups and is the most frequently used clustering technique. Both methods have been successfully used to group oceanic phytoplankton and zooplankton (Thorrington-Smith, 1971; Angel and Fasham, 1973; Wiebe et al., 1976).

Cluster analysis was used to group the similarity coefficients computed for the chaetognaths and euthecosomes. The euphausiid data sets were too small to warrant analysis. The two similarity measures and two clustering techniques defined four classifications per group for each cruise. The applicability of these methods to the data in this study will be discussed in the RESULTS section.

Physical-Biological Data:

All biological data were interpreted in relation to the

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simultaneously collected physical data. The numbers per
1000 m^3 of individual chaetognath, euphausiid and eutheco-
some species were plotted on graphs depicting changes in
the u- (east-west) and v- (north-south) components of velo-
city and temperature, specifically the 10°C and 15°C iso-
therms, during the four sampling periods. This enabled
quick determination of the effects of flow reversals on a
given species. Species dominance and group dominance, using
per cent numbers per 1000 m^3 as an index of dominance, and
species groups delineated by the cluster analysis plots were
also evaluated in terms of the u- and v-components and temper-
ature. An attempt was made to correlate numbers per 1000 m^3
with local density (σ_t) at the level of collection and wind
speed and direction. This, however, proved fruitless because
of insufficient data.

RESULTS

Introduction

Deep current reversals from north to south in the
Florida Straits are low frequency fluctuations which typi-
cally occur over periods of 4 or 5 days and are accompanied
by a 180° shift of the cross-stream component and changes in
volume transport and the slope of the isotherms. During
deep southward flow (SWF), which occurs at times in the en-
tire lower half of the water column, the axis of the Florida
Current shifts to the western side of the Straits with west-
ward-directed cross-stream flow throughout the water column.
This is accompanied by reduced volume transport and a down-
ward displacement of the isotherms. During northward flow
(NWF), flow is to the north in the entire cross-section and
the current shifts eastward with cross-stream flow to the
east, increased volume transport, and a rising and broadening
of the isotherms (Düing, 1975).

The fluctuations of the u- (east-west) and v- (north-
south) components of velocity, mean contours of which are
given in Figs. 6A and 6B, significantly affect the tempera-
ture field (Fig. 6C) with anomalies having a typical ampli-
tude of 2°C. The observed temperature fluctuations, which
are most noticeable in the region approximated by the mean
location of the 10°C and 15°C isotherms (Fig. 7), are caused
by advective horizontal motion. The eastward cross-stream
component causes negative temperature anomalies and the
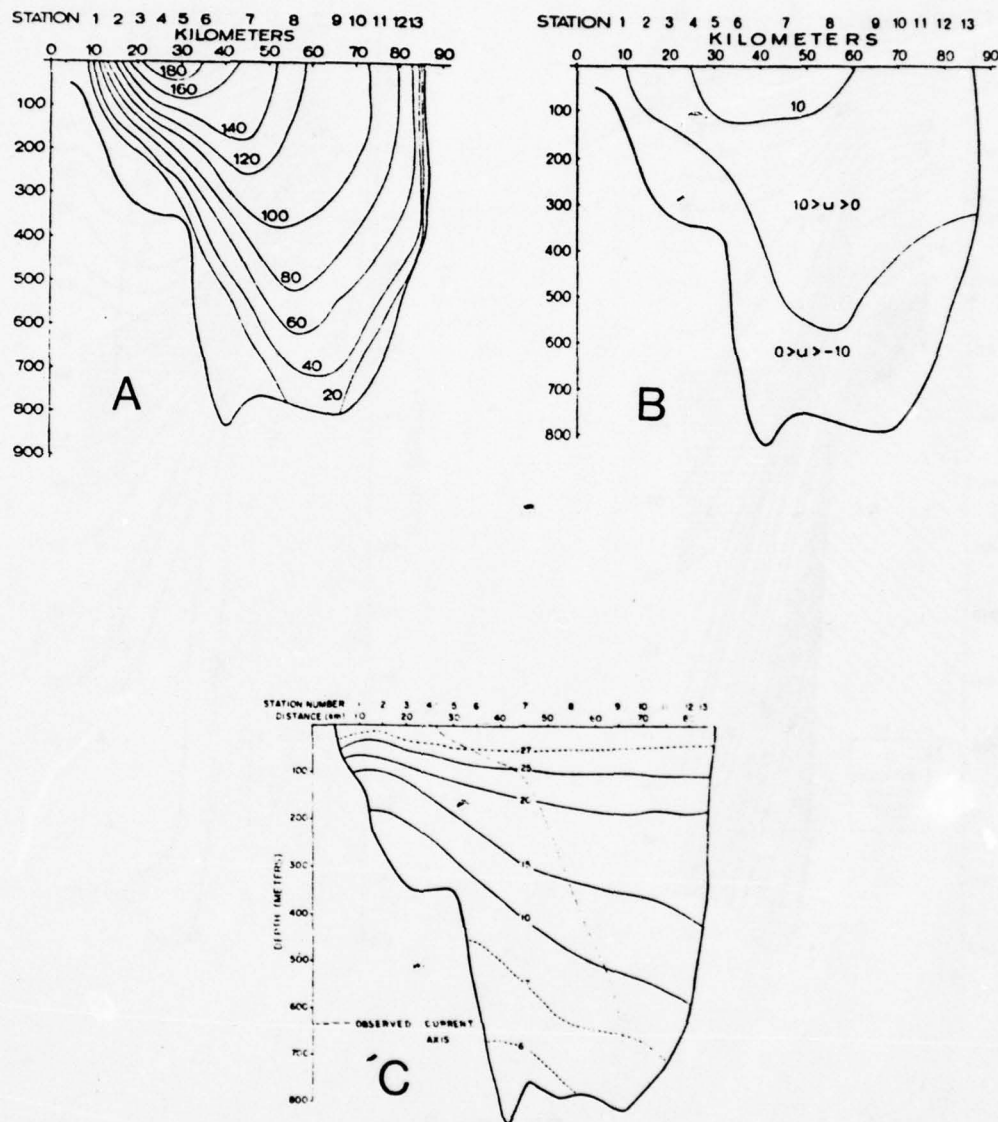
Figure 6

A and B: Summer velocity (cm/sec) of the Florida Current from Miami to Bimini from Niiler and Richardson (1973). A: Northward component. B: Eastward component. C: Mean temperatures (°C) from Miami to Bimini from Stubbs (1971).

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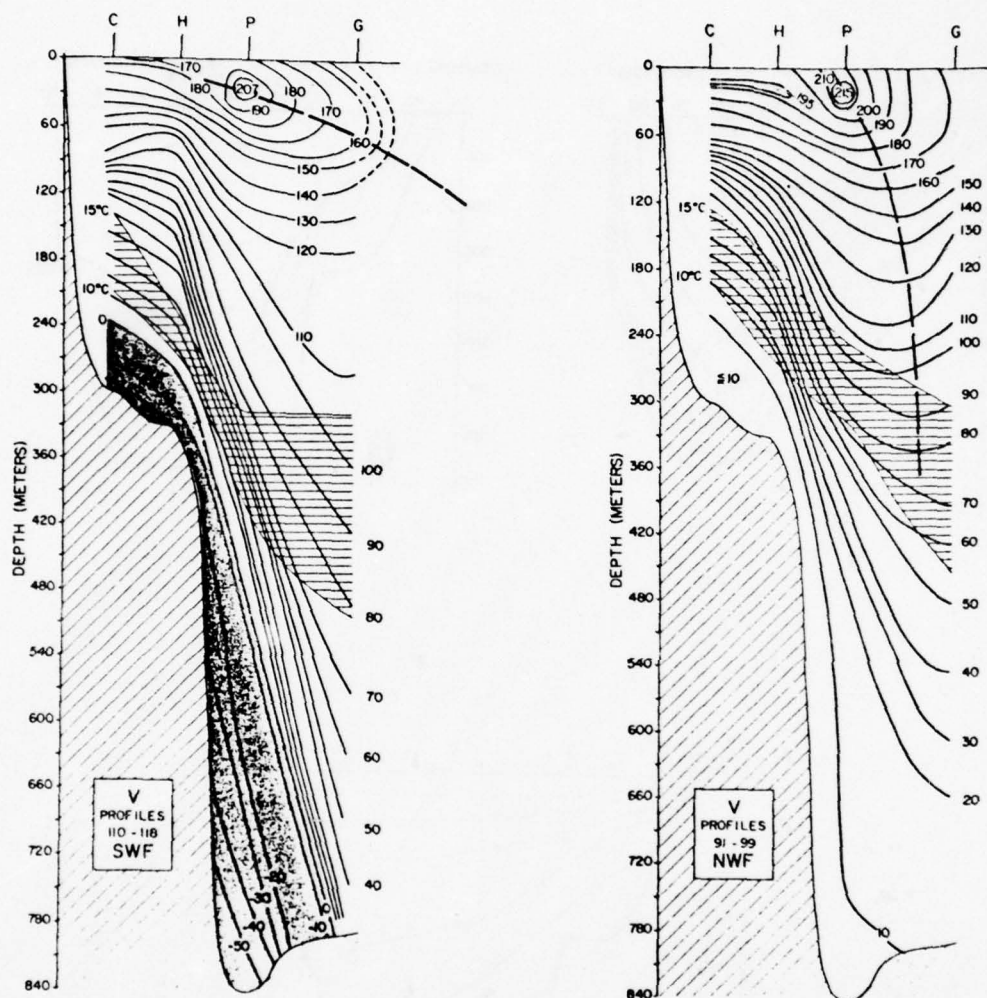
Figure 7

Typical cross-sections of the v-component in the Florida
Straits off Miami from Düing (1975) depicting two extreme
states of the Florida Current: NWF (northward flow) and SWF
(deep southward flow). Shaded areas indicate southward flow.
Horizontally hatched areas indicate the location of the main
thermal front.

westward component, positive anomalies. Thus, the steep, narrow frontal structure typical of deep southward flow is characterized by positive temperature anomalies while the flat, broad temperature structure occurring during northward flow is characterized by negative anomalies.

Düing et al. (1977) analyzed data from a subsurface mooring in the Florida Current off Miami and found positive eddy heat flux toward the east in winter and toward the west in summer. This they interpreted in terms of the seasonal difference in the Florida Current temperature structure. Niiler and Richardson (1973) have shown that the tilt of the isotherms is steeper in summer than in winter. Since a steep, narrow frontal structure (SWF and summer-type) is characterized by positive temperature anomalies and a flat, broad structure (NWF and winter-type) by negative temperature anomalies (Düing, 1975), the positive anomalies noted by Düing et al. (1977) are thought to be advected toward the east in winter and toward the west in summer. The difference between the winter and summer conditions, which correspond respectively to NWF and SWF, has been interpreted by Düing et al. (1977) in terms of different ageostrophic balances. They assume an ageostrophic balance,

$$\frac{du}{dt} - fv = \frac{1}{\rho}\frac{dp}{dx}$$

in a coordinate system where u = eastward flow, v = northward flow, $f = 2\omega \sin \theta$ and dp/dx = the cross-stream pressure gradient. The geostrophic flow, v_g, is given by

$$fv_g = \frac{1}{\rho}\frac{dp}{dx},$$

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resulting in
$$\frac{du}{dt} - f(v-v_g) = 0,$$

where:

$v-v_g = 0$ geostrophic;

$v-v_g > 0$ supergeostrophic flow;

and $v-v_g < 0$ subgeostrophic flow.

Supergeostrophic flow implies an increase in potential energy resulting in a steepening of the front, as seen during deep southward flow (Fig. 7), with downgliding on the upper side toward the east and upgliding on the lower side toward the west (Fig. 8). During subgeostrophic flow, the condition is reversed. There is a decrease in potential energy resulting in a flattening of the front, as observed during northward flow (Fig. 7), with upgliding on the upper side toward the west and downgliding on the lower side toward the east (Fig. 8). Düing et al. (1977) emphasized that there are no direct measurements of the secondary circulation, i.e., no observations of the vertical flow component exist and the conditions described above are based on indirect evidence.

Deep flow reversals and associated meanderings and fluctuations in temperature and transport occur simultaneously. Major spectral peaks occur around periods of 4-6 days and 10-13 days. They are thought to be caused by atmospherically generated continental shelf waves (Schott and Düing, 1976; Düing et al., 1977; Wunsch and Wimbush, 1977).

Continental shelf waves may be induced by atmospheric forcing. The physical mechanism by which wind causes vorticity anomalies which generate "shelf" or other vorticity waves has been explained by Brooks (1975), who investigated

28

N

NWF
SUBGEOSTROPHIC

SWF
SUPERGEOSTROPHIC
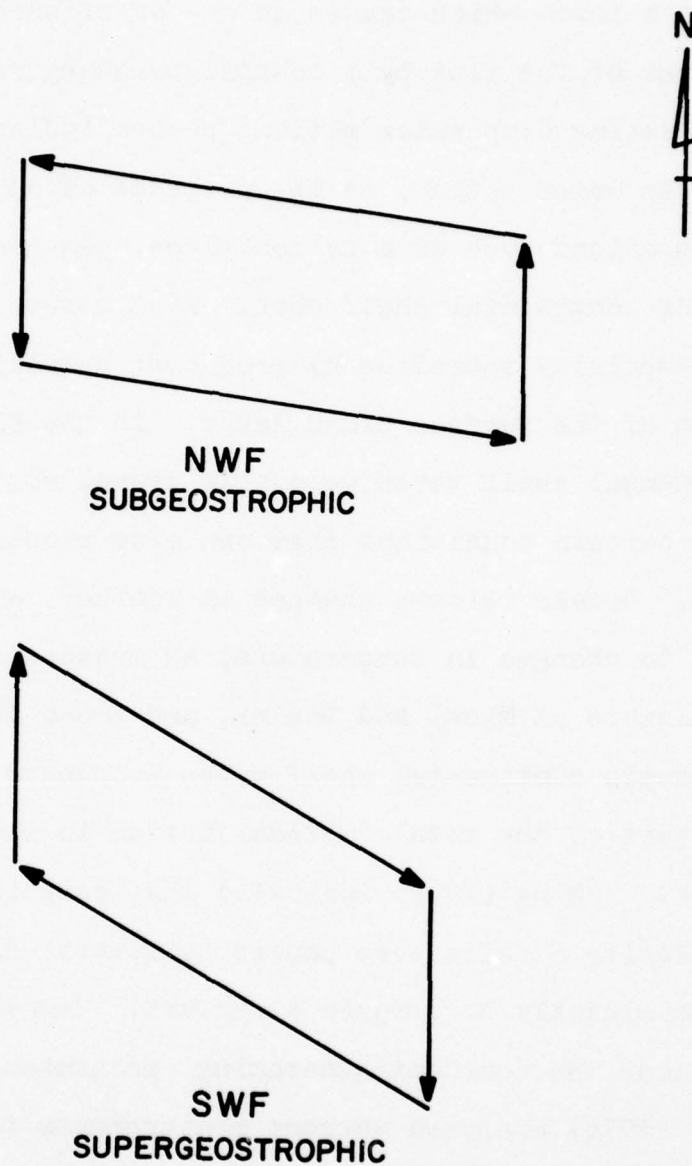
Figure 8

Frontal circulation in the Florida Current off Miami during
periods of northward flow (NWF) and deep southward flow
(SWF).

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meteorological forcing by the wind as a mechanism for generating subtidal fluctuations in the Florida Current. The wind exerts a force which causes an on- or offshore Ekman flux. Blockage of the flux by a coastal boundary results in mass-compensating deep water motions perpendicular to the coast. The deep water motion, in the presence of an external vorticity gradient such as a bottom slope, can generate a vorticity or continental shelf wave. Wind stress can also cause deep vorticity anomalies by producing upwelling at the bottom of the surface Ekman layer. In the Florida Current, continental shelf waves generally travel southward, although under certain conditions they can also propagate to the north. Brooks related changes in weather, wind, and sea level to changes in temperature, as measured by strings of thermistors at Miami and Bimini, and found that wind-forced barotropic continental shelf waves accounted for a significant part of the total subtidal motion in the Florida Current. Düing (1975) indicated that deep flow reversals in the Florida Straits were caused by several-day waves having a predominantly barotropic structure. However, he could not determine the dominant generating mechanism. Schott and Düing (1976) analyzed current measurements from the Florida east coast for the presence of propagating waves and concluded that the fluctuations they observed were barotropic continental shelf waves, and Düing et al. (1977) found that analysis of temperature and current measurements from sub-surface moorings in the Florida Current revealed properties

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consistent with the barotropic continental shelf wave theory.

Deep flow reversals, with their associated conditions of super- and subgeostrophy, occur when the wind-induced continental shelf wave is superimposed on the mean baroclinic profile of the Florida Current. In the simplest case, as described by Düing (1975), "a wave with an amplitude of approximately 15 cm/sec, constant in depth and time, and a period of 5 days shifts the mean baroclinic profile of the Florida Current back and forth. Since the deep mean flow is nearly zero, temporary southward flow results." Conditions, of course, are not always as simple as this hypothetical case but it serves to illustrate the mechanism generating deep flow fluctuations in the Florida Straits.

In view of the present knowledge of deep flow reversals summarized above, the current meter data for each of my data sets will be discussed separately in terms of changes in the u- and v-components of velocity and temperature with particular emphasis on the 10°C and 15°C isotherms. All data will then be examined in terms of seasonal changes, density (σ_t), and atmospheric forcing. The water mass present at the level of the deep plankton collections will be identified. The distribution patterns of the chaetognaths, euthecosomes, and euphausiids in the deep samples will then be interpreted in relation to these data. Thus, a description of the changing physical and biological characteristics of the deep current during the four sampling periods will emerge. Station data for each data set are given in Appendix I, Tables 1-4.

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Deep Flow Reversals

Profiling Current Meter Data:

CI-7206: Time-depth contour plots of the u- and v-
components of velocity and temperature from 300 m to the
bottom during CI-7206 (Fig. 1, Table 1) are based on 38 con-
secutive profiles taken at 6-hr intervals (Figs. 9, 10 and
11). Contours for the v-component (Fig. 9) show two periods
of deep southward flow (SWF) separated by a period of north-
ward flow (NWF) in the entire column and a transition period
between NWF and SWF. Profiles (P) 1-7 represent the end of
a period of SWF which extended from 345 m to the bottom.
This was followed by approximately 2 days of NWF (P 8-15)
and a 2-day transition period between NWF and SWF charac-
terized by small puses of SWF (P 16-22). During P 23, the
current reversed and continued flowing to the south through
the end of the sampling period 4 days later. This pulse of
SWF extended, at times, through half the water column
(350 m) and attained bottom velocities as high as 46 cm/sec
to the south.

The u-component (Fig. 10) showed changes from east to
west which corresponded to north-south changes in the v-
component. P 1-5 indicated a brief period of weak flow to
the east followed by a period of stronger flow to the west.
During the 2-day period spanned by P 6-14, flow was generally
to the east throughout the water column, corresponding to a
northward oriented v-component. The cross-stream flow in
P 15-38 was westerly. A shift from east to west occurred

32
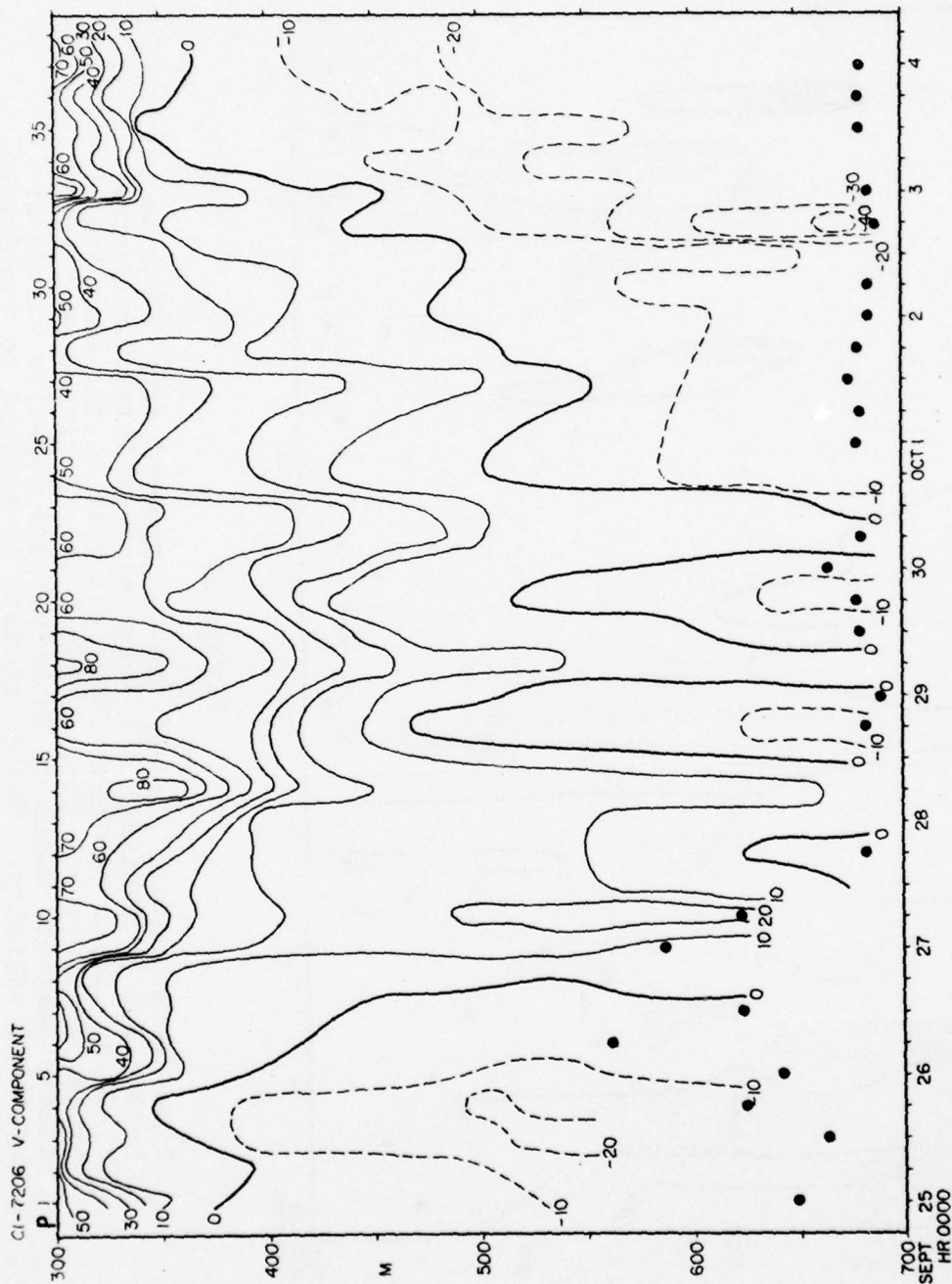
Figure 9

Time-depth contour plot of the v-component from 300 m to the bottom for 38 profiles (P) taken at 5-hr intervals during CI-7206. Solid contours represent flow to the north and broken contours are flow to the south. Positive numbers indicate northward velocity in cm/sec and negative values are southward velocity. The black dots correspond to the depths of the deep plankton collections.
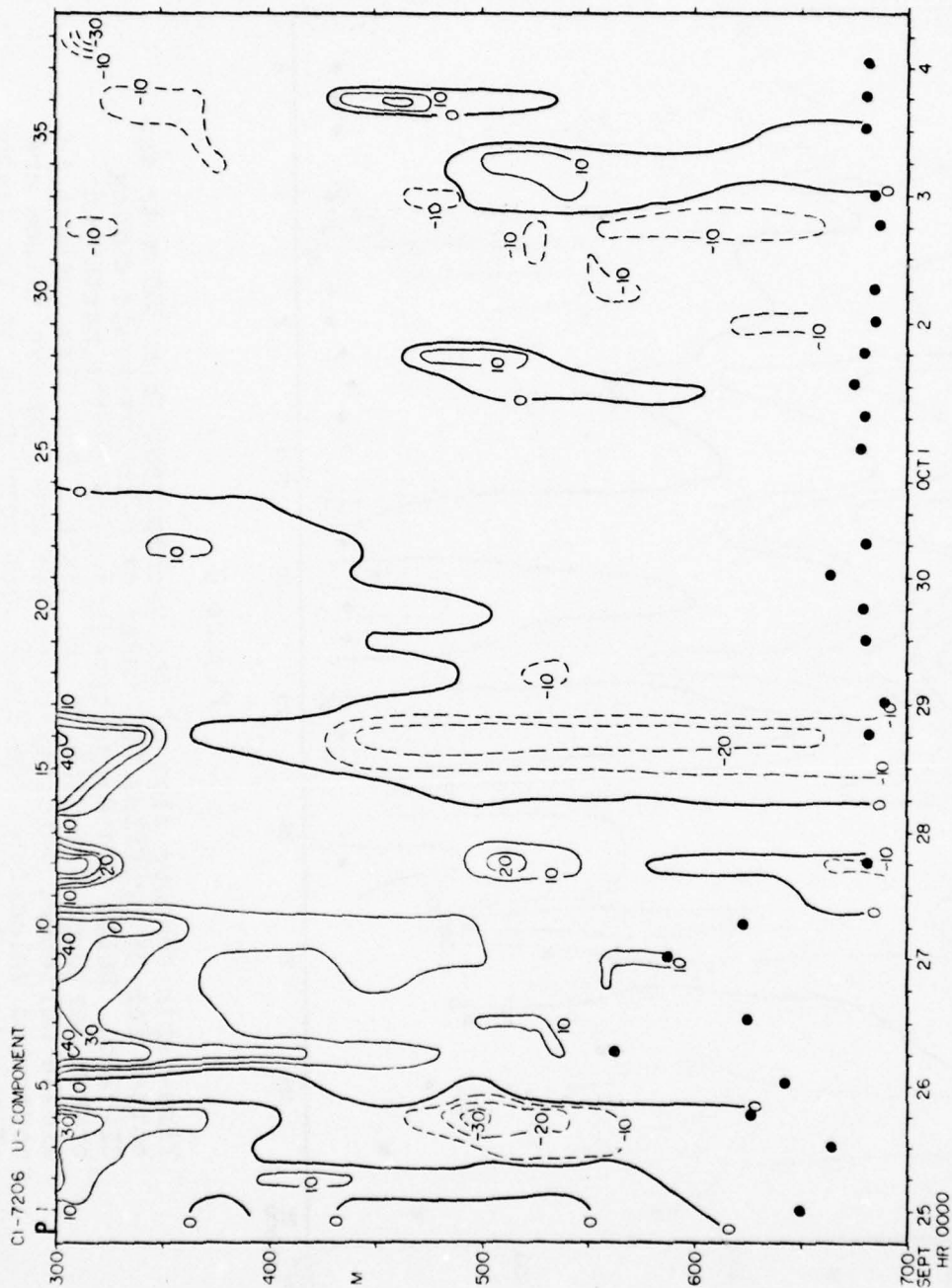
Figure 10

Time-depth contour plot of the u-component from 300 m to the bottom for 38 profiles (P) taken at 6-hr intervals during CI-7206. Solid contours represent flow to the east and broken contours are flow to the west. Positive numbers indicate eastward velocity in cm/sec and negative values are westward velocity. The black dots correspond to the depths of the deep plankton collections.

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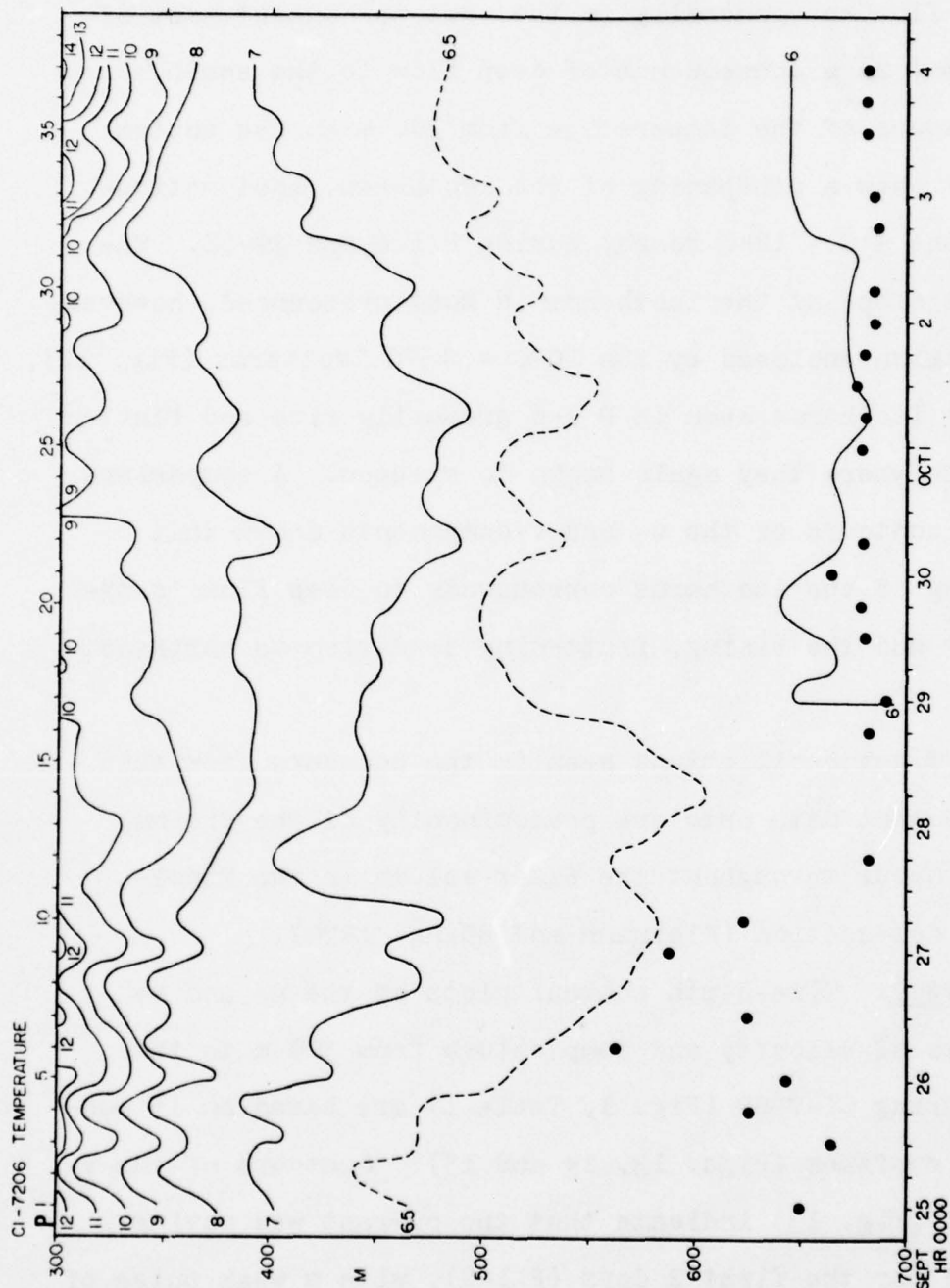
Figure 11

Time-depth contour plot of temperature from 300 m to the
bottom for 38 profiles (P) taken at 6-hr intervals during
CI-7206. The black dots correspond to the depths of the
deep plankton collections.

from 450 m to the bottom during P 15-24 and corresponds to the transition from north to south seen in Fig. 9, P 16-22. By P 24, flow was generally to the west throughout most of the column, as a consequence of deep flow to the south.

Contours of the temperature from 300 m to the bottom (Fig. 11) show a steepening of the isotherms, most notice-able in the 9°C - 12°C range, during P 1-6 and 29-38. The change in slope of the isotherms is most pronounced, however, in the region enclosed by the 10°C - 15°C isotherms (Fig. 12), where the isotherms seen in P 1-6 gradually rise and flatten until P 24 where they again begin to steepen. A comparison with the contours of the u- and v-components shows that steepening of the isotherms corresponds to deep flow to the southwest and the rising, flattening condition to northeast flow.

The tidal oscillations seen in the contours from this and subsequent data sets are predominantly of the diurnal type and occur throughout the water column in the Miami-Bimini cross-section (Kielmann and Düing, 1974).

CI-7309: Time-depth contour plots of the u- and v-components of velocity and temperature from 300 m to the bottom during CI-7309 (Fig. 1, Table 1) are based on 15 con-secutive profiles (Figs. 13, 14 and 15). Contours of the v-component (Fig. 13) indicate that the current was moving northward for the first 2 days (P 1-8), with a weak pulse of SWF (<10 cm/sec) occurring during P 3-5, and southward for the remainder of the time series (P 9-15). Cross-stream flow

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Figure 12

Time-depth contour plot of temperature in the region of the 10°C - 15°C isotherms for 38 profiles (P) taken at 6-hr intervals during CI-7206.
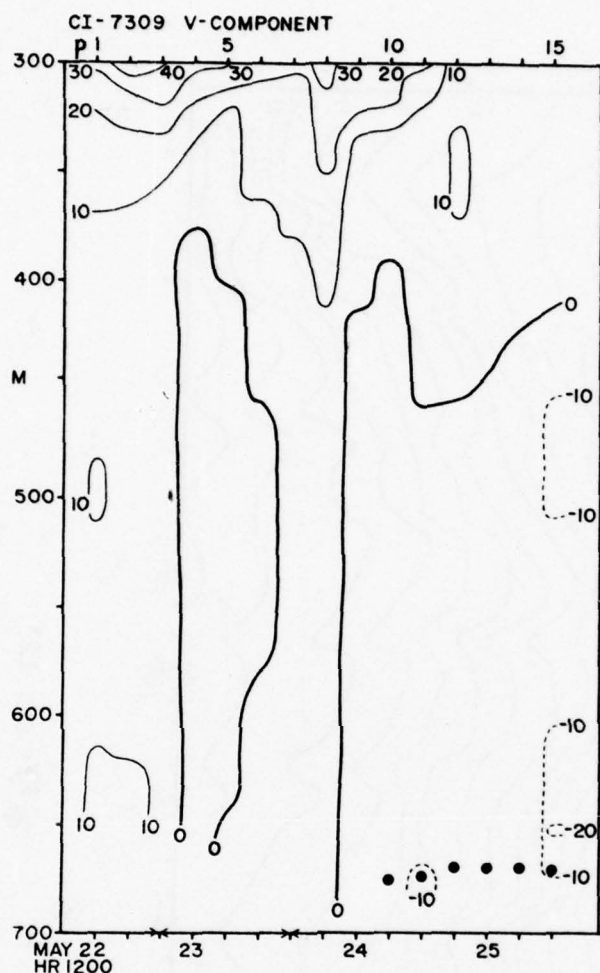
Figure 13

Time-depth contour plot of the v-component from 300 m to the bottom for 15 profiles (P) taken at 6-hr intervals during CI-7309. Solid contours represent flow to the north and broken contours are flow to the south. Positive numbers indicate northward velocity in cm/sec and negative values are southward velocity. The black dots correspond to the depths of the deep plankton collections. Symbols (→×←) indicate profiles taken out of the usual sampling sequence (0000, 0600, 1200, and 1800 hrs) at 2100 (P 3) and 1500 (P 7).

38
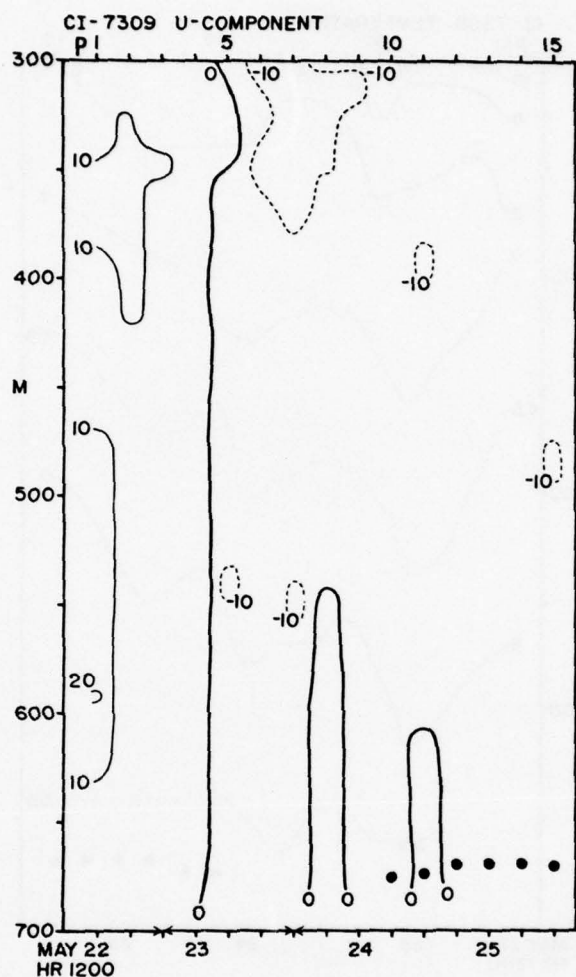
Figure 14

Time-depth contour plot of the u-component from 300 m to
the bottom for 15 profiles (P) taken at 6-hr intervals
during CI-7309. Solid contours represent flow to the east
and broken contours are flow to the west. Positive numbers
indicate eastward velocity in cm/sec and negative values
are westward velocity. The black dots correspond to the
depths of the deep plankton collections. Symbols (→←)
indicate profiles taken out of the usual sampling sequence
(0000, 0600, 1200, and 1800 hrs) at 2100 (P 3) and 1500
(P 7).

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Figure 15

Time-depth contour plot of temperature from 300 m to the bottom for 15 profiles (P) taken at 6-hr intervals during CI-7309. The black dots correspond to the depths of the deep plankton collections. Symbols (→✕←) indicate profiles taken out of the usual sampling sequence (0000, 0600, 1200, and 1800 hrs) at 2100 (P 3) and 1500 (P 7).

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(Fig. 14) was oriented eastward in P 1-4 and westward during P 5-15. The change in direction from east to west corresponds to the north-south reversal and thus results in overall flow to the northeast or southwest.

The sloping of the isotherms is not as marked in the deep temperature contours (Fig. 15) as in the 150-350 m range (Fig. 16), the region enclosed by the 10°C and 15°C isotherms. Here, the typical isotherm structure associated with flow reversals, i.e., rising and broadening of the isotherms during northeastward flow (P 1-8) and steepening of the structure during flow to the southwest (P 9-15), is evident.

CI-7317: Time-depth contour plots of the u- and v-components of velocity and temperature from 300 m to the bottom during CI-7317 (Fig. 1, Table 1) are based on 12 consecutive profiles (Figs. 17, 18 and 19). Contours of the v-component (Fig. 17) indicate that intense SWF, with velocities at times exceeding 50 cm/sec, occurred during the entire 3-day time series. The u-component (Fig. 18) was strongly directed toward the west and the isotherms (Figs. 19 and 20) were noticeably steepened in response to the deep southwestward flow.

CI-7401: Time-depth contour plots of the u- and v-components of velocity and temperature from 300 m to the bottom during CI-7401 (Fig. 1, Table 1) are based on 15 consecutive profiles (Figs. 21, 22 and 23). Contours of the v-component (Fig. 21) indicate that strong SWF prevailed, with small pulses of NWF at P 4 and P 8. A total reversal began

41
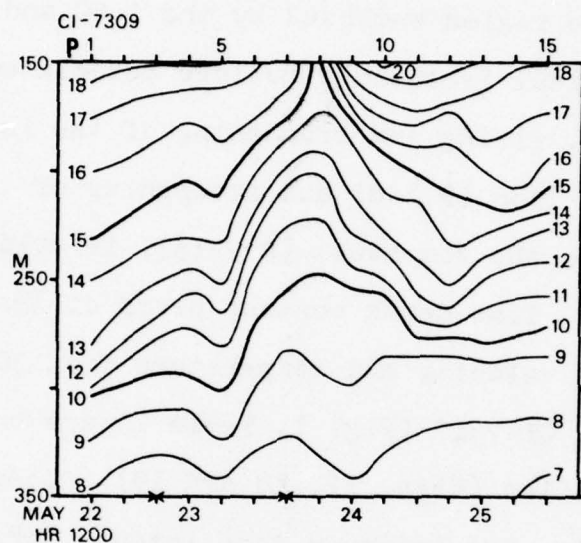
CI-7309

Figure 16

Time-depth contour plot of temperature in the region of the
10°C - 15°C isotherms for 15 profiles (P) taken at 6-hr in-
tervals during CI-7309. Symbols (→←) indicate profiles
taken out of the usual sampling sequence (0000, 0600, 1200,
and 1800 hrs) at 2100 (P 3) and 1500 (P 7).
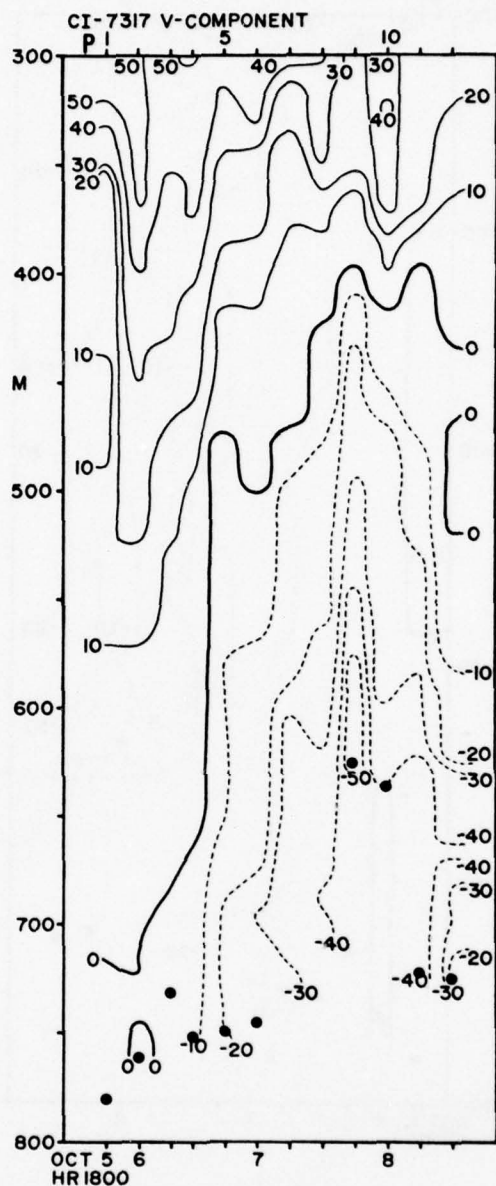
Figure 17

Time-depth contour plot of the v-component from 300 m to
the bottom for 12 profiles (P) taken at 6-hr intervals
during CI-7317. Solid contours represent flow to the north
and broken contours are flow to the south. Positive numbers
indicate northward velocity in cm/sec and negative values
are southward velocity. The black dots correspond to the
depths of the deep plankton collections.

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Figure 18

Time-depth contour plot of the u-component from 300 m to
the bottom for 12 profiles (P) taken at 6-hr intervals
during CI-7317. Solid contours represent flow to the east
and broken contours are flow to the west. Positive numbers
indicate eastward velocity in cm/sec and negative values
are westward velocity. The black dots correspond to the
depths of the deep plankton collections.

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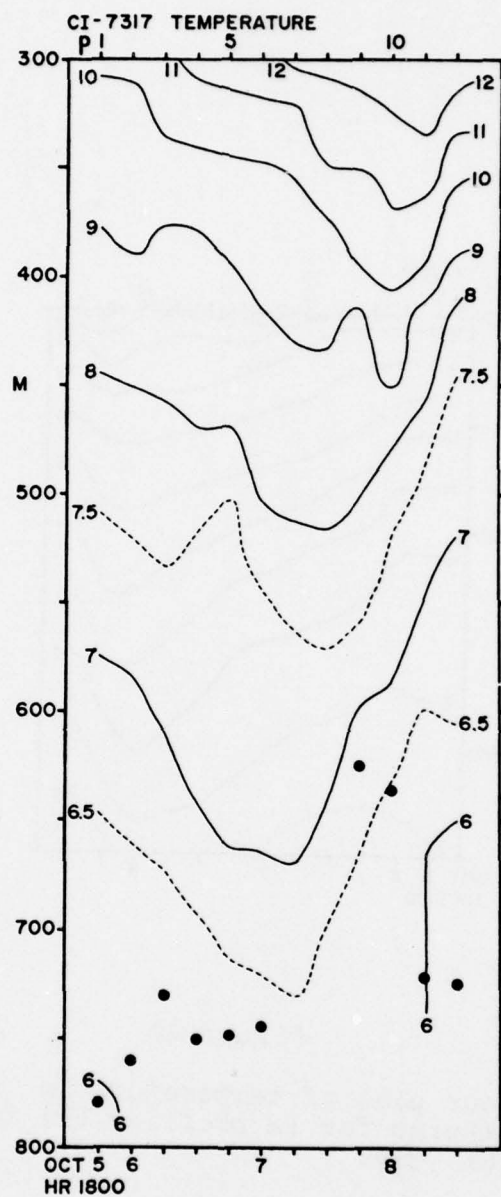
Figure 19

Time-depth contour plot of temperature from 300 m to the bottom for 12 profiles (P) taken at 6-hr intervals during CI-7317. The black dots correspond to the depths of the deep plankton collections.
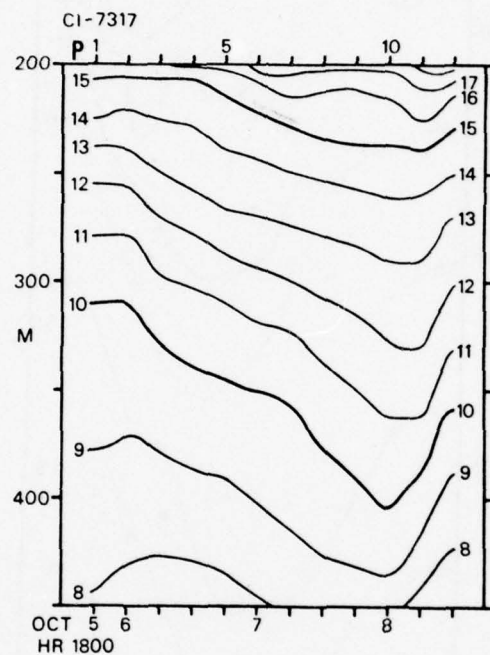
Figure 20

Time-depth contour plot of temperature in the region of the 10°C - 15°C isotherms for 12 profiles (P) taken at 6-hr intervals during CI-7317.

Figure 21

Time-depth contour plot of the v-component from 300 m to
the bottom for 15 profiles (P) taken at 6-hr intervals
during CI-7401. Solid contours represent flow to the north
and broken contours are flow to the south. Positive num-
bers indicate northward velocity in cm/sec and negative
values are southward velocity. The black dots correspond
to the depths of the deep plankton collections.

47
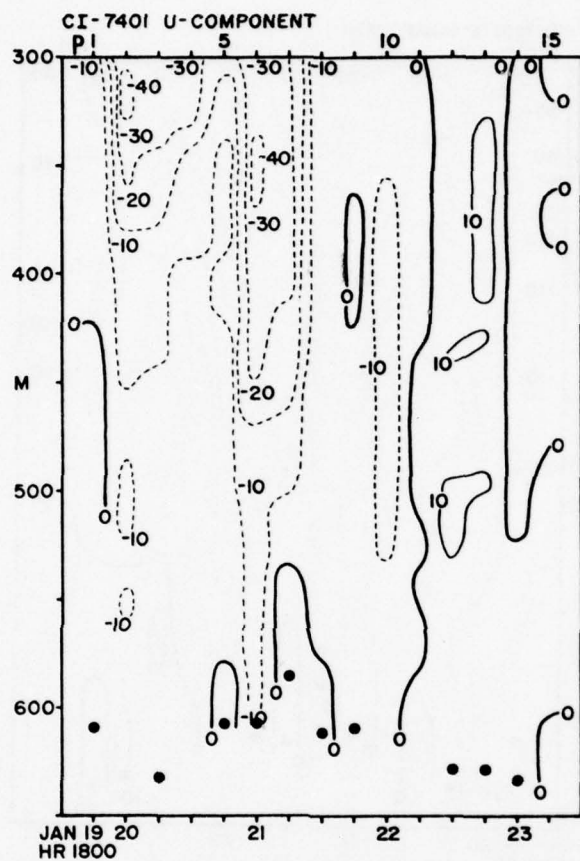
Figure 22

Time-depth contour plot of the u-component from 300 m to the bottom for 15 profiles (P) taken at 6-hr intervals during CI-7401. Solid contours represent flow to the east and broken contours are flow to the west. Positive numbers indicate eastward velocity in cm/sec and negative values are westward velocity. The black dots correspond to the depths of the deep plankton collections.

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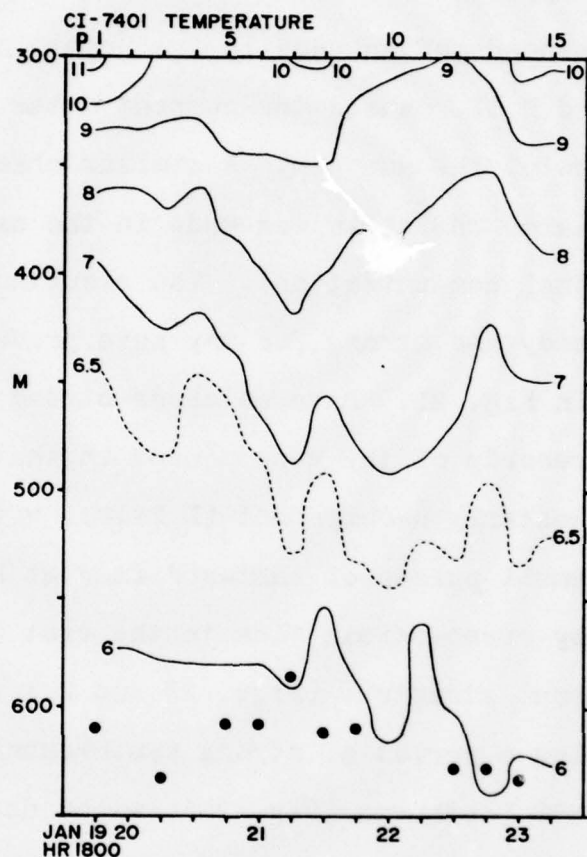
Figure 23

Time-depth contour plot of temperature from 300 m to the bottom for 15 profiles (P) taken at 6-hr intervals during CI-7401. The black dots correspond to the depths of the deep plankton collections.

at P 11 and continued through the end of the series 1 day later. The arrangement of the v-component isopleths varies considerably from those in the other 3 data sets (Figs. 9, 13 and 17) in that the direction of flow in most of the water column appears to be oriented southward. This may be due to the presence of an eddy in the upper layers which, during P 4 and P 12, caused the current meter to indicate southward flow at the surface. A similar observation of surface flow towards the south was made in the same area by T. Lee (personal communication). The simultaneous occurrence of an eddy and strong SWF may have produced the situation shown in Fig. 21. Data on cross-stream flow (Fig. 22) support the records of the v-component in that SWF is accompanied by a westerly u-component (P 1-10), with the exception of two small pulses of eastward flow at P 5 and P 7 and 8, and NWF, by cross-stream flow to the east (P 11-15).

The thermal structure (Figs. 23 and 24) varied from that expected during a period of strong southwesterly flow in that the 10°C - 15°C isotherms (Fig. 24), which usually steepen in response to SWF, are actually rising and broadening, possibly in response to the beginning of NWF seen in Fig. 21, P 4, 8 and 11-15. In addition, the presence of the eddy may have considerably altered the thermal structure.

Each of the four data sets thus shows variations in currents below 300 m similar to those found by previous investigators. Reversals of varying intensity occur at several-day intervals. When the v-component is directed

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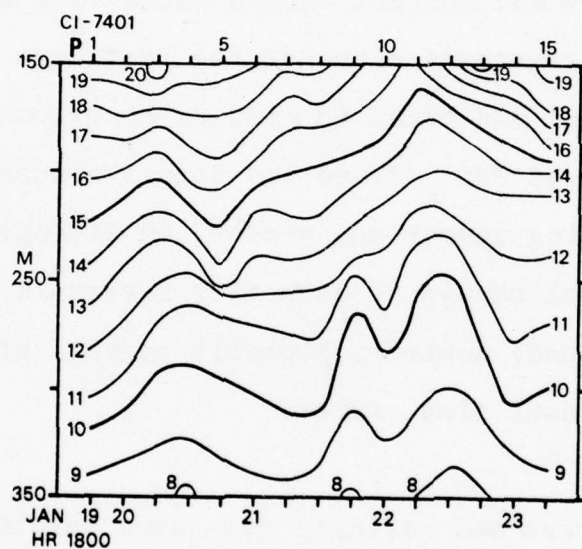
Figure 24

Time-depth contour plot of temperature in the region of the
10°C - 15°C isotherms for 15 profiles (P) taken at 6-hr in-
tervals during CI-7401.

toward the north, the u-component is easterly, and the thermal structure in the region of the 10°C - 15°C isotherms is flat and broad. When the v-component is oriented toward the south, cross-stream flow is westerly, and the thermal structure in the region of the 10°C - 15°C isotherms steepens.

Seasonal Changes:

Düing et al (1977), in a study based on 2-year records of temperature and current from a subsurface mooring, have found that the average slope of the isotherms is steep in summer and flat and broad in winter, corresponding to conditions of SWF and NWF. Since the data discussed here were collected during summer and winter, an attempt was made to relate seasonal change to deep flow reversals. No correlation was found, however, probably because of the shortness of the individual time series.

Density (σ_t):

Temperature and salinity data were obtained at each station by using a water bottle equipped with reversing thermometers. Data are available from only one depth at each station. This is usually at the level of plankton sampling, noted by black dots in Figs. 9-23. Occasionally a bottle pre-tripped in shallower water, and in several instances no data are available due to equipment malfunction. From these measurements, σ_t at sampling depth was calculated and plotted against time to determine if flow reversals affected density. It was thought that the frontal circulation thought to be associated with changes in the thermal

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structure (subgeostrophic vs. supergeostrophic) might cause variations in density (σ_t). Examination of the data (Table 3) shows no direct relationship, although slight correlations are sometimes evident. For example, during CI-7206, data from 600-700 m (Table 4) show σ_t values of 27.62, 27.64, and 27.64 for profiles (P) 5, 6 and 10. These values, with the exception of P 29 (σ_t 27.68), are higher than those computed for comparable depths later in the time series. The corresponding temperatures for P 5, 6 and 10 are, for the most part, lower than those recorded for the later profiles, although the salinity does not seem to vary significantly. Data from P 12-30 were collected during the end of a period of NWF lasting until P 15, a transition period between NWF and SWF (P 16-22) and a period of SWF beginning at P 23 and and continuing through P 30 (Fig. 9). Perhaps the lower σ_t values and higher temperatures observed during P 12-30 are the result of shallower water being advected downward along the lower edge of the thermal front (subgeostrophic condition) during the earlier period of NWF (P 8-15). Due to a time lag, the changes in σ_t and temperature would be seen later in the time series as is the case here. This type of variation does not depart greatly from the mean density anomaly in the Straits (Fig. 25) and is not always apparent (Table 3), perhaps due to the small number and random nature of the measurements. It is therefore not possible to determine if it is significant here.

Table 3

Sigma-t (σ_t) computed from temperature and salinity
measurements obtained during CI-7206, CI-7309,
CI-7317, and CI-7401.

Cruise	Date	Time (EDT)	Profile No.	Depth (m)	Sigma-t (σ_t)
CI-7206	25 Sept 72	0600	2	536	25.51
		1200	3	571	27.56
	26 Sept	0000	5	659	27.62
		0600	6	619	27.64
		1200	7	278	26.86
	27 Sept	0600	10	621	27.64
		1800	12	660	27.47
	28 Sept	0000	13	699	27.52
		0600	14	637	27.53
	29 Sept	0000	17	624	27.50
	30 Sept	0000	21	660	27.50
		0600	22	629	27.57
	1 Oct	0000	25	618	27.53
		1200	27	662	27.54
		1800	28	689	27.54
	2 Oct	0000	29	635	27.68
		0600	30	648	27.52
	4 Oct	0000	37	593	27.56
CI-7309	22 May 73	1200	1	593	27.46
	23 May	0000	4	310	27.03
		0600	5	348	27.24
	24 May	0000	9	494	27.43
		1200	11	674	27.59
		1800	12	684	27.61
	25 May	0000	13	683	27.53
		0600	14	678	27.53
		1200	15	677	27.60
CI-7317	6 Oct 73	0000	2	791	27.47
		1200	4	770	27.46
		1800	5	771	27.47
	7 Oct	0000	6	770	27.47
		1200	8	732	27.56
		1800	9	637	27.39
	8 Oct	0600	11	745	27.50
		1200	12	742	27.49
CI-7401	19 Jan 74	1800	1	537	27.50
	20 Jan	0000	2	294	27.22
		1800	5	629	27.56
	21 Jan	0600	7	623	27.53

Table 3
(continued)

Cruise	Date	Time (EDT)	Profile No.	Depth (m)	Sigma-t (σ_t)
		1200	8	629	27.53
		1800	9	590	27.51
	22 Jan	1200	12	647	27.52
		1800	13	653	27.79
	23 Jan	0000	14	653	27.51
		0600	15	655	27.54
		1200	16	641	27.51
		1800	17	651	27.50
	24 Jan	0000	18	625	27.49
		0600	19	602	27.78
		1200	20	599	27.47
		1800	21	632	27.50
	25 Jan	0000	22	647	27.57

Table 4

Temperature, salinity, and σ_t data from 600-700 m obtained during CI-7206.

Date	Time (EDT)	Profile No.	Depth (m)	Temperature (°C)	Salinity (°/oo)	Sigma-t (σ_t)
26 Sept 72	0000	5	659	6.08	35.073	27.62
	0600	6	619	6.07	35.081	27.64
27 Sept	0600	10	621	6.13	35.087	27.64
	1800	12	660	6.26	34.901	27.47
28 Sept	0000	13	699	6.14	34.937	27.52
	0600	14	637	6.30	34.975	27.53
29 Sept	0000	17	624	6.34	34.964	27.50
30 Sept	0000	21	660	6.28	34.944	27.50
	0600	22	629	6.24	35.016	27.57
1 Oct	0000	25	618	6.16	34.953	27.53
	1200	27	662	6.22	34.980	27.54
	1800	28	689	6.00	34.961	27.54
2 Oct	0000	29	635	6.36	35.187	27.68
	0600	30	648	6.28	34.971	27.52
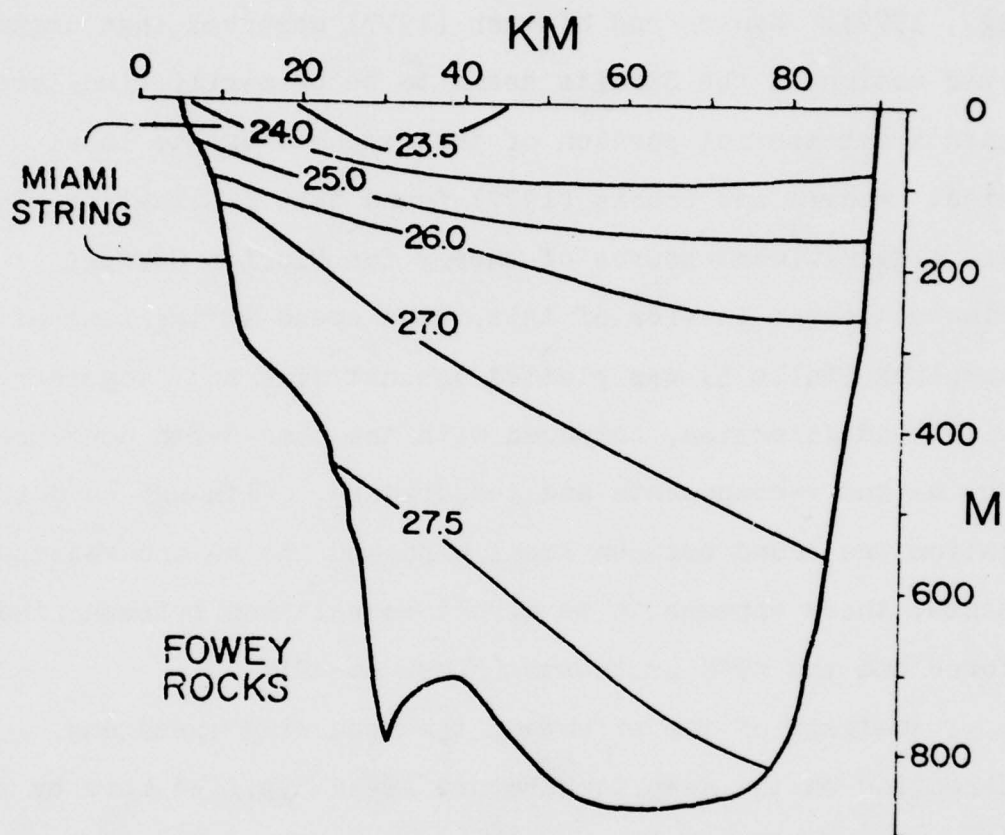
Figure 25

Mean density anomaly (σ_t) between Fowey Rocks and Cat Cay from Brooks (1975). "Miami string" indicates the location of a string of thermistors used by Brooks.

Wind Speed and Direction:

As discussed earlier, deep flow reversals in the Florida Current appear related to wind-induced barotropic continental shelf waves (Brooks, 1975; Schott and Düing, 1976; Düing et al., 1977). Wunsch and Wimbush (1977) observed that organized motion in the Straits seems to be primarily wind-forced, with a substantial portion of the response due to local wind. Mooers and Brooks (1977) found that fluctuating winds are a significant source of energy for Florida Current fluctuations. In view of this, wind speed at the time of sampling (Table 5) was plotted against time and, together with wind direction, compared with the time-depth contours of the u- and v-components and temperature. Although no correlation was found between local wind and the u- and v-components, there appears to be direct correlation between wind force and the <9°C isotherms (Figs. 26-29).

Analysis of the effect of the mean wind speed and direction on the deep temperature field typified here by the 7°C isotherm (Table 6) provides a possible explanation for this correlation. During each sampling period the wind was from the S or SE, being more easterly during CI-7206 and CI-7401 and more southerly during CI-7309 and CI-7317. The correlation between wind speed and the 7°C isotherm in Figs. 26-29 is best for CI-7206 and CI-7401 (Figs. 26 and 29), where the mean wind is from 117° and 116° with an average force of 11 and 10 kts, and least similar in CI-7309 (Fig. 27), where the wind is from 186° at 9 kts. While the deep

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Table 5

Wind observations taken at 6-hr intervals during CI-7206, CI-7309, CI-7317, and CI-7401.

Cruise	Profile No.	Wind Direction (from)	Wind Force (kts)
CI-7206	1	E	12
	2	E	12
	3	E	13
	4	E	14
	5	E	12
	6	E	12
	7	E	10
	8	E	12
	9	SE	10
	10	E	14
	11	SE	14
	12	SE	14
	13	SE	14
	14	E	12
	15	No Data	No Data
	16	E	6
	17	E	14
	18	E	13
	19	E	10
	20	E	10
	21	E	10
	22	E	6
	23	S	4
	24	S	10
	25	S	10
	26	SW	6
	27	SW	2
	28	SE	6
	29	SE	10
	30	SE	6
	31	SE	8
	32	SE	6
	33	E	14
	34	E	13
	35	E	16
	36	E	10
	37	E	20
	38	SE	10
CI-7309	1	SW	3
	2	SE	8
	3	SE	10
	4	SE	8

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Table 5
(continued)

Cruise	Profile No.	Wind Direction (from)	Wind Force (kts)
	5	SW	3
	6	SE	16
	7	S	8
	8	S	10
	9	SW	11
	10	SW	5
	11	S	6
	12	SW	12
	13	SW	14
	14	SW	10
	15	S	12
CI-7317	1	SE	5
	2	S	2
	3	NW	10
	4	No Wind	0
	5	E	2
	6	E	4
	7	SW	2
	8	S	4
	9	SE	6
	10	SE	10
	11	SE	6
	12	SE	8
CI-7401	1	SE	6
	2	SE	10
	3	SE	14
	4	SE	14
	5	SE	12
	6	SE	10
	7	SE	12
	8	SE	10
	9	SE	6
	10	SE	4
	11	SE	4
	12	SE	6
	13	SE	6
	14	E	14
	15	SE	15
	16	SE	14
	17	E	8
	18	E	16
	19	E	16
	20	E	14
	21	E	12
	22	NE	6

60
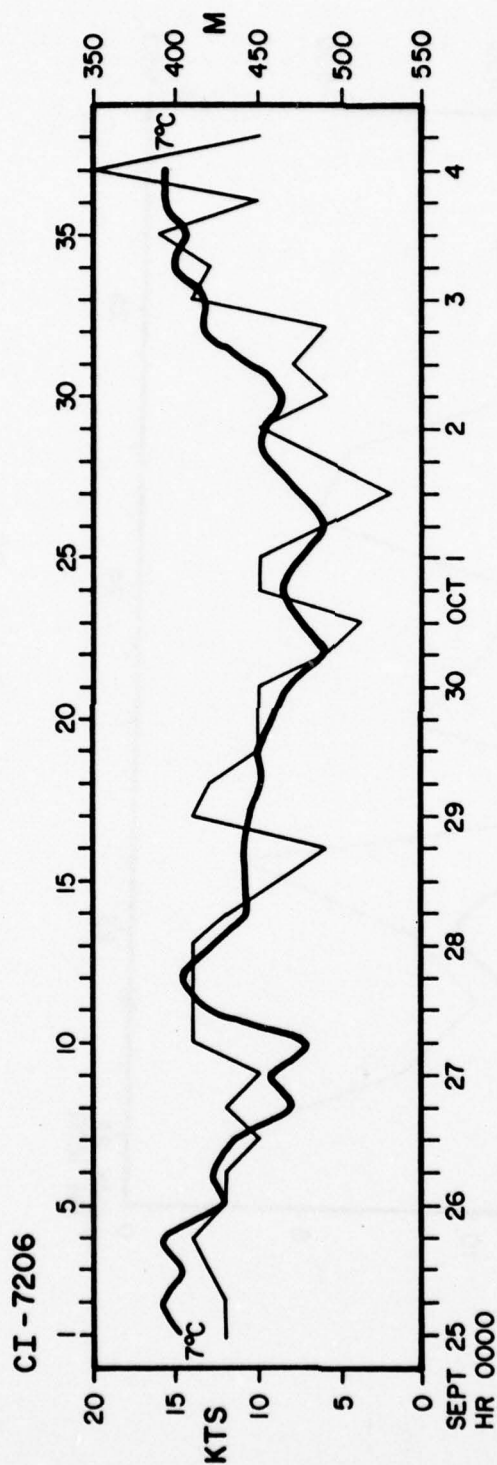
Figure 26

Variations in the wind speed and 7°C isotherm during CI-7206. Wind force, obtained from the bridge at 6-hr intervals, corresponds to sampling times. Temperatures are from the current meter data.

61
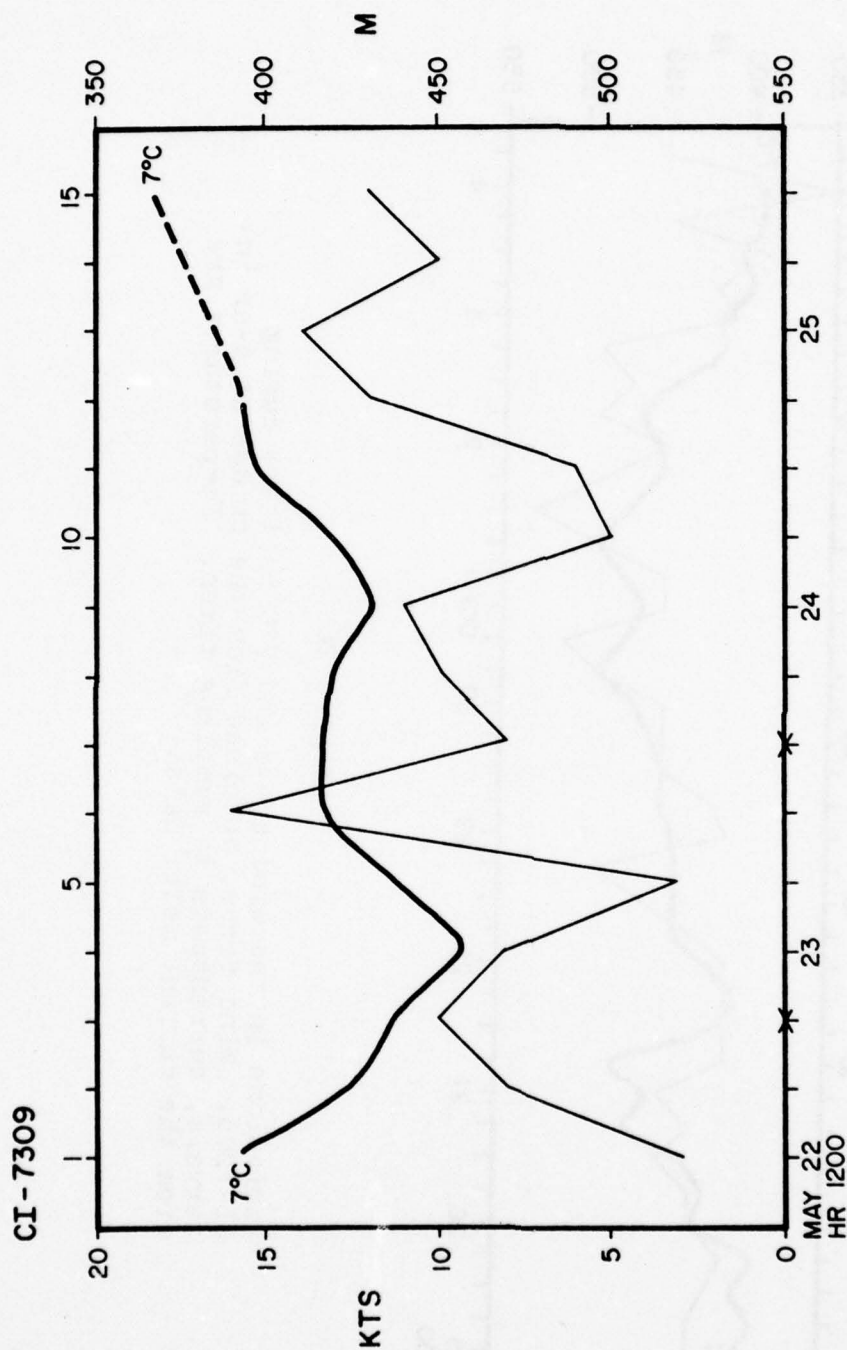
Figure 27

Variations in the wind speed and 7°C isotherm during
CI-7309. Wind force, obtained from the bridge at 6-hr in-
tervals, corresponds to sampling times. Temperatures are
from the current meter data. Symbols (—*—) indicate
readings taken out of the usual sampling sequence (0000,
0600, 1200, and 1800 hrs) at 2100 (P 3) and 1500 (P 7).

62
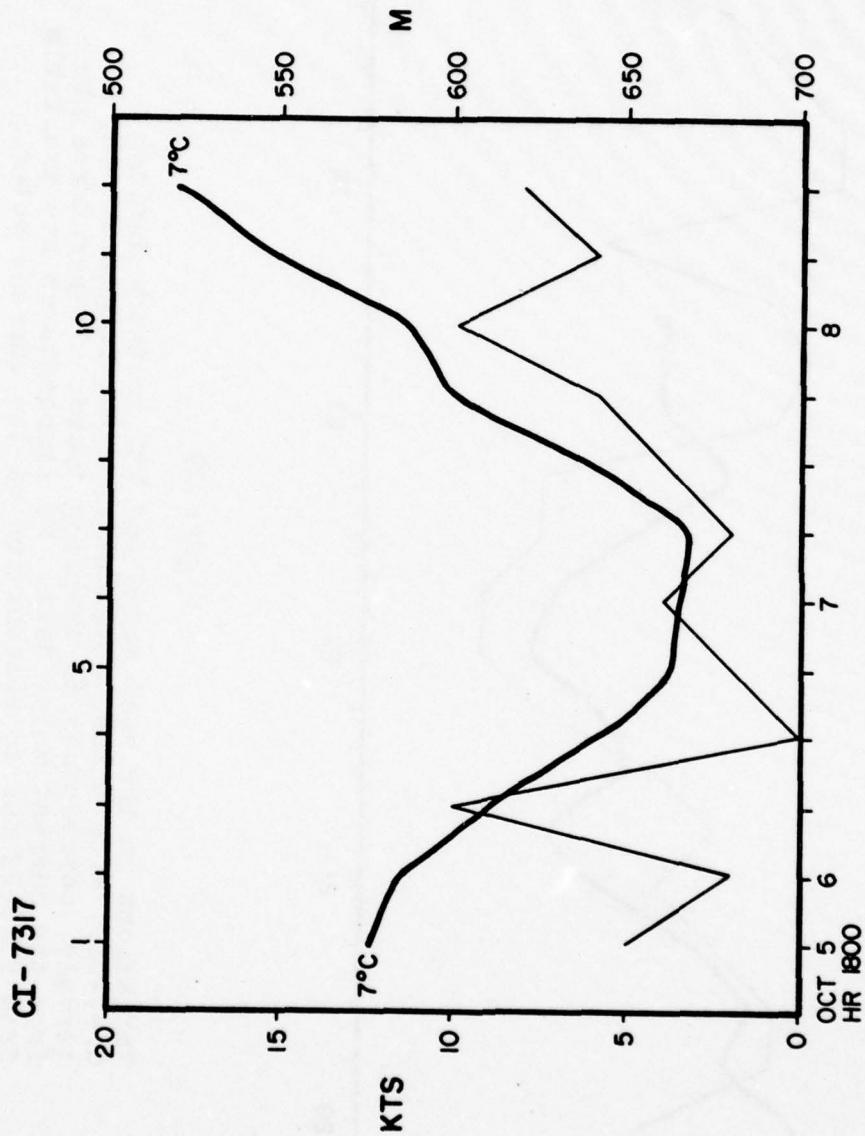
Figure 28

Variations in the wind speed and 7°C isotherm during CI-7317. Wind force, obtained from the bridge at 6-hr intervals, corresponds to sampling times. Temperatures are from the current meter data.

63
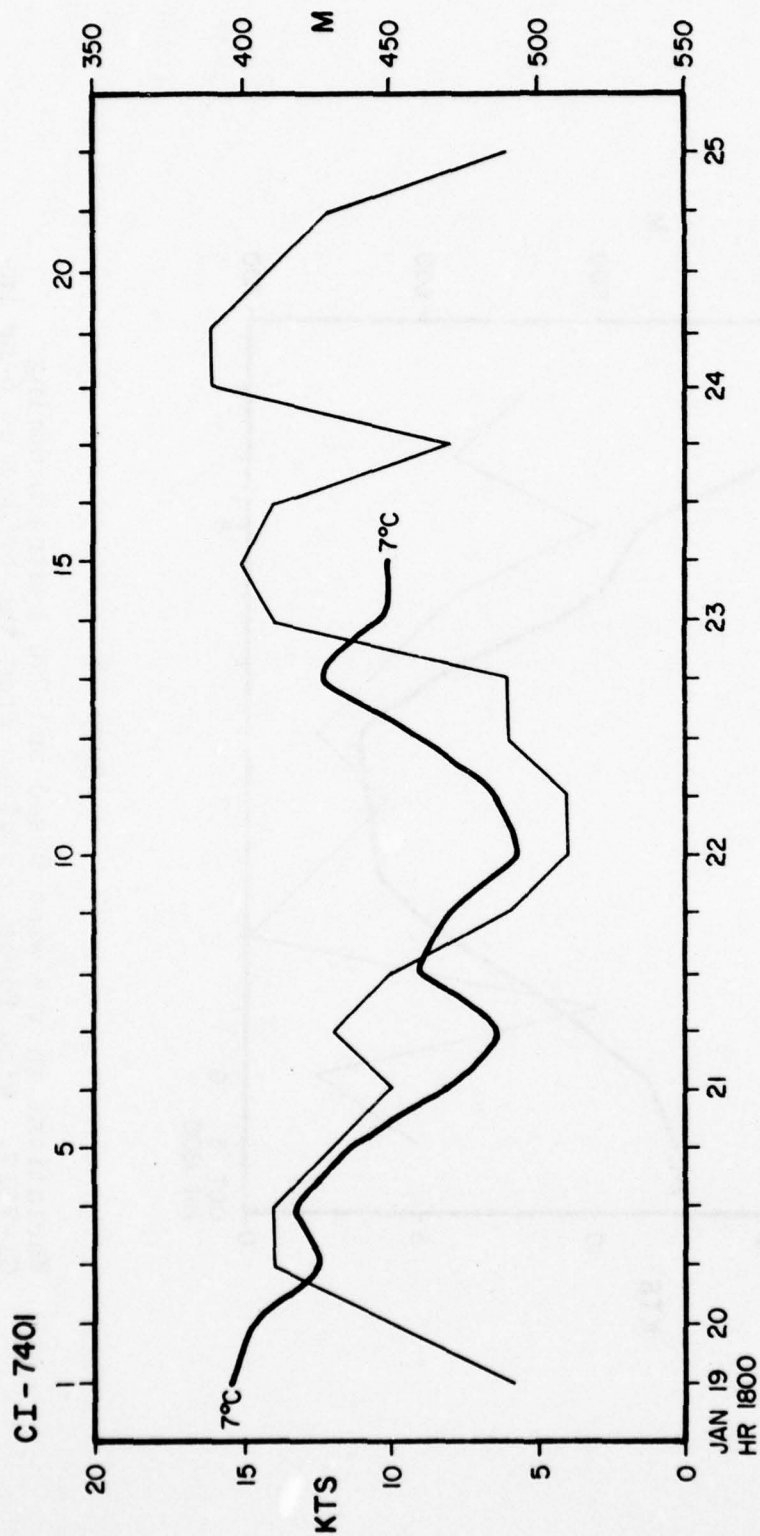
Figure 29

Variations in the wind speed and 7°C isotherm during CI-7401. Wind force, obtained from the bridge at 6-hr intervals, corresponds to sampling times. Temperatures are from the current meter data. No temperatures are available from P 16-22 due to malfunction of the current meter.

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Table 6

Range of the 7°C isotherm and the mean wind direction and speed during CI-7206, CI-7309, CI-7317, and CI-7401.

Cruise	Range of 7°C Isotherm (m)	Mean Wind Direction (° from)	Mean Wind Force (kts)
CI-7206	390-495	117	11
CI-7309	365-460	186	9
CI-7317	520-670	158	5
CI-7401	395-495	116	10

isotherms in CI-7309 did not respond to wind speed as did those monitored during CI-7206 and CI-7401, they did show a more pronounced uplifting of the isotherms. During CI-7309, the range of the 7°C isotherm (365-460 m) is shallower than that of CI-7206 (390-495 m) and CI-7401 (395-495 m). The thermal field on both sides of the Straits is known to respond to wind events in accordance with coastal upwelling and downwelling theory (Brooks, 1975). Thus, winds from the south on the Miami side of the Straits generate an offshore Ekman transport in the surface layers which results in up-welling and a rise in the isotherms. It follows then, as is shown here, that in the Florida Straits off Miami, southerly winds (CI-7309: 186°) would uplift the isotherms to a greater extent than more easterly winds (CI-7206: 117°; CI-7401: 116°). Correlation between wind force and deep temperatures seen when more easterly winds predominate (Figs. 26 and 29) may be masked by the stronger upwelling response during periods of southerly winds. The situation in CI-7317 (Fig. 28) appears anomalous. The range of the 7°C isotherm is deeper than CI-7206 and CI-7401 despite the mean wind being from 158°. Perhaps wind speed contributed to this anomaly since the average speed during CI-7317 is only 5 kts as com-pared to 11, 9 and 10 kts for CI-7206, CI-7309, and CI-7401.

The deep thermal field in the Straits off Miami thus appears to be affected by both wind direction and speed. This correlation is important when considering deep current reversals because wind-induced changes in the thermal field

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generate barotropic continental shelf waves (Brooks, 1975)
which, when superimposed on the mean baroclinic profile of
the Florida Current, contribute to the occurrence of the
deep flow reversals.

Water Masses:

Three water masses have been distinguished in the
Straits of Florida: Tropical Surface Water, Subtropical
Underwater or Maximum Salinity Water, and Subantarctic Inter-
mediate Water. They are part of a transient system composed
of waters from the southern half of the North Equatorial
Current and a branch of the South Equatorial Current. This
water flows through the Caribbean and exits at the Yucatan
Channel. Here it enters the Gulf of Mexico in the form of a
loop, which undergoes an annual cycle of growth and decay
(Leipper, 1970; Maul, 1977) and passes through the Florida
Straits along its insular margin in nearly its original
state. Fig. 30, modified from Stubbs (1971), shows the
typical T-S curves for Tropical Surface Water, Subtropical
Underwater, and Subantarctic Intermediate Water between
Miami and Bimini. A fourth water mass may be present in the
Straits. Examination of typical T-S diagrams for the North
Atlantic reveals a close correspondence between deep cold
water in the Straits of Florida and Subarctic Water (E. Cor-
coran, personal communication). If Subarctic Water is pre-
sent, then part of the water involved in flow reversals
would originate in deep oceanic areas to the north.

All samples in the present study were collected in Sub-

67
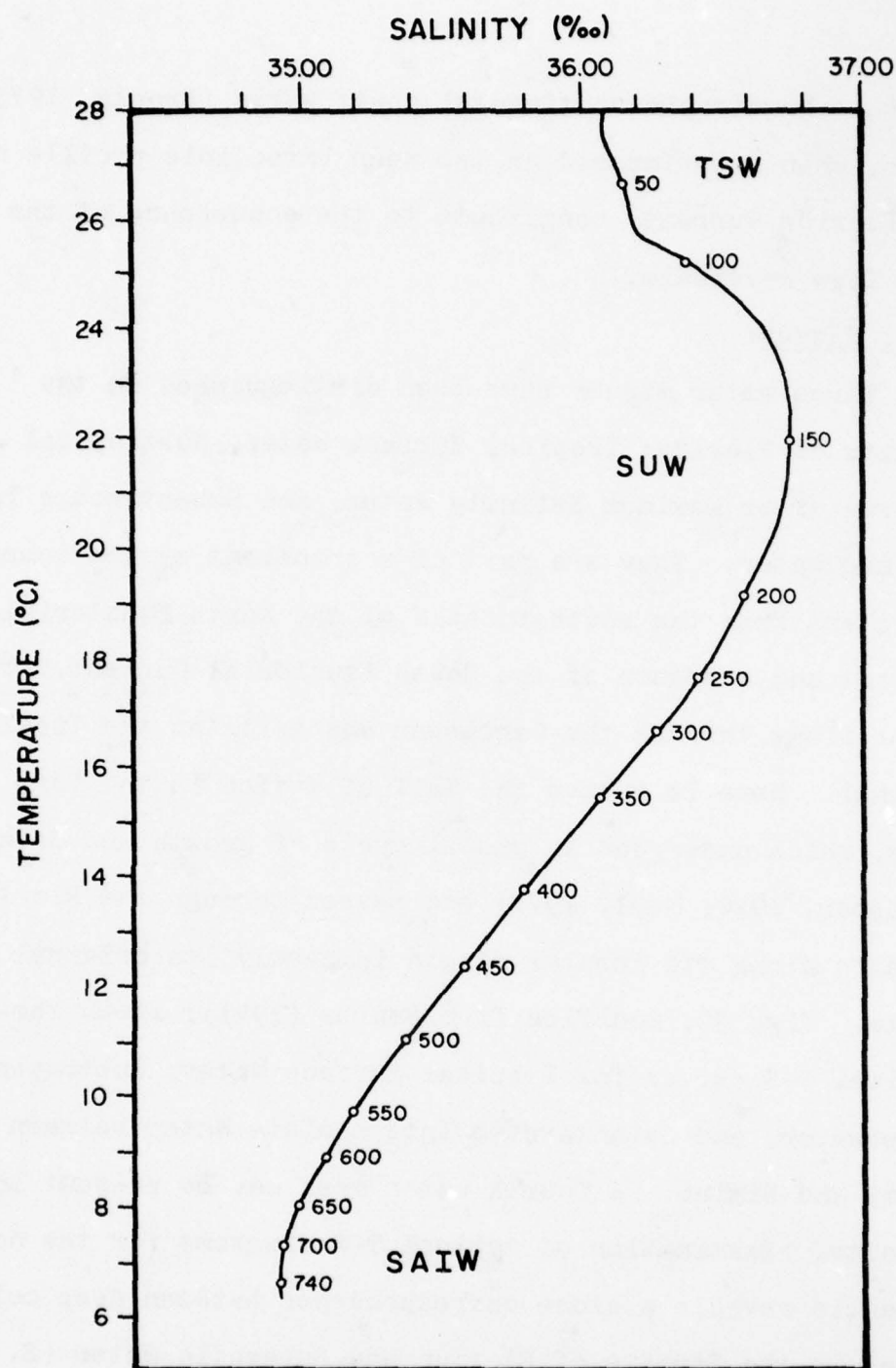
Figure 30

T-S diagram, modified from Stubbs (1971), of the water
masses in the Straits of Florida (TSW: Tropical Surface
Water; SUW: Subtropical Underwater; SAIW: Subantarctic
Intermediate Water).

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antarctic Intermediate Water, which is characterized by
temperature and salinity values ranging from 5°C to 8°C and
34.69 °/$_{oo}$ to 35.12 °/$_{oo}$ (Wüst, 1964). The temperature at
the depth of sampling, at times as low as 5.3°C, usually
averaged 6°C. The salinity ranged from 34.884 °/$_{oo}$ to
35.303 °/$_{oo}$, with only five values above 35.12 °/$_{oo}$.

Although the deep reversals, with the exception of the
atypical situation in CI-7401, occurred primarily in the
deep cold water mass, knowledge of the shallower water
masses is also important in this study. Since both the sub-
and supergeostrophic conditions induced by deep flow rever-
sals postulate upgliding and downgliding along the edges of
a thermal front roughly delimited by the 10°C - 15°C iso-
therms, the shallower water masses would be involved in the
secondary circulation.

Chaetognatha

The horizontal and vertical distribution patterns of
chaetognaths are specific characters which make the group
particularly useful in indicating changing hydrologic condi-
tions. A species may be cosmopolitan or endemic to a parti-
cular water mass; it may be neritic or oceanic; or, it may
inhabit either the epi-, meso-, or bathypelagic zones. As
will be shown below, the distribution of many of the
chaetognaths collected in the deep samples varies from the
known patterns and thus provides information on changing
physical conditions in the Florida Straits.

Twenty species representing four genera were identified from the samples. These are:

Eukrohnia bathyantarctica David, 1958

E. bathypelagica Alvariño, 1962

E. fowleri Ritter-Záhony, 1909

E. hamata (Möbius, 1875)

Krohnitta pacifica (Aida, 1897)

K. subtilis (Grassi, 1881)

Pterosagitta draco (Krohn, 1853)

Sagitta bipunctata Quoy and Gaimard, 1827

S. decipiens Fowler, 1905

S. enflata Grassi, 1881

S. helenae Ritter-Záhony, 1910

S. hexaptera d'Orbigny, 1843

S. hispida Conant, 1895

S. lyra Krohn, 1853

S. macrocephala Fowler, 1905

S. megalopthalma Dallot and Ducret, 1969

S. minima Grassi, 1881

S. serratodentata Krohn, 1853

S. tenuis Conant, 1896

S. zetesios Fowler, 1905

All have been reported from either the Florida Straits or the Caribbean, Gulf of Mexico, and the North Atlantic off the continental United States (Table 7) although five, Eukrohnia bathyantarctica, E. bathypelagica, Sagitta megalopthalma, S. tenuis, and S. zetesios, are new records for the Straits

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Table 7

Previous records from the Caribbean, Gulf of Mexico, Florida Straits, and the North Atlantic off the continental United States of chaetognath species reported in this study. Additional records of Atlantic distribution have been summarized by Alvariño (1969) and Michel et al. (1976).

Species	Caribbean[1]	Gulf of Mexico[2]	Florida Straits[3]	North Atlantic off continental United States[4]
Eukrohnia bathyantarctica	+	+	-	-
E. bathypelagica	+	+	-	-
E. fowleri	+	+	+	+
E. hamata	+	+	+	+
Krohnitta pacifica	+	+	+	+
K. subtilis	+	+	+	+
Pterosagitta draco	+	+	+	+
Sagitta bipunctata	+	+	+	+
S. decipiens	+	+	+	+
S. enflata	+	+	+	+
S. helenae	+	+	+	+

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Table 7
(continued)

Species	Caribbean[1]	Gulf of Mexico[2]	Florida Straits[3]	North Atlantic off continental United States[4]
S. hexaptera	+	+	+	+
S. hispida	+	+	+	+
S. lyra	+	+	+	+
S. macrocephala	+	+	+	+
S. megalopthalma	+	-	-	-
S. minima	+	+	+	+
S. serratodentata	+	+	+	+
S. tenuis	+	+	-	+
S. zetesios	+	-	-	+

[1]Vanucci and Hosoe (1952); Suárez-Caabro (1955); Colman (1959); Suárez-Caabro and Madruga (1960); Legaré and Zoppi (1961); Alvariño (1968); Fagetti (1968); Lewis and Fish (1969); Björnberg (1971); Owre (1972, 1973); Owre and Foyo (1972); Mattlin (1974); Urosa and Rao (1974); Michel et al. (1976).

[2]Davis (1949); King (1949); Pierce (1951, 1954, 1962); Every (1968); Fagetti (1968); Mulkana and McIlwain (1973); Owre (1973).

Table 7
(continued)

[3]Owre (1960).

[4]Bigelow and Sears (1939); Redfield and Beale (1940); Moore (1949);
Pierce (1953, 1958); Bumpus and Pierce (1955);Colman (1959); Deevey (1960);
Grice and Hart (1962); Pierce and Wass (1962); Grant (1963 a,b, 1977);
Deevey and Brooks (1971).

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off Miami.

On the basis of known horizontal and vertical distribution patterns, the species reported here, with the exception of *S. megalopthalma*, can be classified as epipelagic neritic, epipelagic oceanic, mesopelagic oceanic, and meso-bathypelagic oceanic (Table 8). The division of species into neritic and oceanic is well-documented (Alvariño, 1965); however, the levels of bathymetric distribution are more arbitrary. This problem has been discussed by Michel et al. (1976), and the classification scheme used here is based on their findings in the Caribbean and on Owre's (1960) work in the Florida Straits. Of the twenty species collected in the deep samples, ten are well-known epipelagic forms and three of the ten are neritic, not oceanic. The former group consists of *Krohnitta pacifica*, *Pterosagitta draco*, *Sagitta bipunctata*, *S. enflata*, *S. hexaptera*, *S. minima*, and *S. serratodentata*, and the neritic species are *Sagitta helenae*, *S. hispida*, and *S. tenuis* (Pierce, 1951, 1953, 1958; Bumpus and Pierce, 1955; Owre, 1960; Pierce and Wass, 1962; Grant, 1963 a,b, 1977). A number of these species were also found below 600 m in the same area by Owre (1960). The presence of epipelagic (0-200 m) species at this depth in the Straits is a distributional anomaly especially in combination with the typically meso- and meso-bathypelagic species *Eukrohnia bathyantarctica*, *E. bathypelagica*, *E. fowleri*, *E. hamata*, *Krohnitta subtilis*, *Sagitta decipiens*, *S. lyra*, *S. macrocephala*, and *S. zetesios* (Michel et al., 1976). These

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Table 8

Bathymetric distribution of chaetognath species reported in
this study based on findings of Michel et al. (1976).

	Neritic	Oceanic
Epipelagic (0-200 m)	Sagitta helenae S. hispida S. tenuis	Krohnitta pacifica Pterosagitta draco Sagitta bipunctata S. enflata S. hexaptera S. megalopthalma[5] S. minima S. serratodentata
Mesopelagic (100-600 m)		K. subtilis S. decipiens S. lyra S. megalopthalma[5] S. zetesios
Meso-Bathypelagic (>500-600 m)		Eukrohnia bathyantarctica E. bathypelagica E. fowleri E. hamata S. macrocephala

[5]Insufficient data are available to assign S. mega-
lopthalma to a specific bathymetric zone. It has been
collected in small numbers at both the epi- and mesopelagic
levels.

unusual associations of chaetognaths were found in samples collected in periods of SWF during all four surveys (Tables 9-12). For example, CI-7206, sample 20, consists of two oceanic epipelagic species, Sagitta bipunctata and S. enflata, one neritic species, S. helenae, and one meso-bathypelagic species S. macrocephala; CI-7309, sample 15, yielded four oceanic epipelagic chaetognaths, S. enflata, S. hexaptera, S. minima, and S. serratodentata and two meso-bathypelagic species, Eukrohnia fowleri and S. macrocephala; CI-7317, sample 9, had two oceanic epipelagic forms, Pterosagitta draco and S. enflata, one mesopelagic form, S. lyra, and four meso-bathypelagic forms. E. bathypelagica, E. fowleri, E. hamata, and S. macrocephala; CI-7401, sample 6, had two oceanic epipelagic species, S. enflata and S. serratodentata, one mesopelagic species, Krohnitta subtilis, and two meso-bathypelagic species, E. fowleri and S. macrocephala. These combinations of species collected at 600 m during deep flow reversals indicate that the current near bottom consists not only of deep Atlantic water but also of shallower waters from both coastal and oceanic areas. In fact, the numbers of the two commonest bathypelagic species collected in the deep samples, E. fowleri and S. macrocephala, are similar to and at times actually exceeded by the two most common epipelagic species in the Straits off Miami, S. enflata and S. serratodentata (Owre, 1960) (Tables 9-12 and Appendix II, Tables 3, 11, 16 and 19).

The presence of neritic and epipelagic oceanic species

Table 9

Percentages of chaetognath species in samples collected during CI-7206.

CI-7206	Station Number												
	1	3	4	5	6	7	9	10	12	16	17	19	20
Eukrohnia bathyantarctica	-	-	-	-	-	-	-	-	-	-	-	-	-
E. bathypelagica	-	-	-	-	-	-	-	-	-	5.0	-	-	-
E. fowleri	25.0	33.3	6.5	-	-	-	-	-	-	35.0	-	-	-
E. hamata	-	8.3	-	-	-	-	-	-	-	-	-	-	-
Krohnitta pacifica	-	-	-	-	-	-	-	-	-	-	-	-	-
K. subtilis	-	-	-	-	-	-	-	37.5	-	-	-	-	-
Pterosagitta draco	-	-	-	-	-	-	-	-	-	-	-	-	-
Sagitta bipunctata	-	-	3.2	-	-	-	-	-	-	-	-	-	3.1
S. decipiens	-	8.3	3.2	-	-	-	-	-	-	-	-	-	-
S. enflata	-	-	16.1	-	-	54.5	-	-	-	-	-	-	81.2
S. helenae	-	-	-	-	-	-	-	-	-	-	-	-	3.1
S. hexaptera	-	-	3.2	20.0	-	18.2	-	-	50.0	-	-	25.0	-
S. hispida	-	-	-	-	-	-	-	-	-	-	-	-	-
S. lyra	-	-	-	-	-	-	-	-	-	-	-	-	-
S. macrocephala	75.0	50.0	3.2	-	-	18.2	-	-	50.0	55.0	-	75.0	12.5
S. megalopthalma	-	-	-	-	-	-	-	-	-	-	-	-	-
S. serratodentata	-	-	64.5	80.0	-	9.1	100.0	62.5	-	5.0	-	-	-
S. tenuis	-	-	-	-	-	-	-	-	-	-	100.0	-	-
S. zetesios	-	-	-	-	-	-	-	-	-	-	-	-	-
Total Number per 1000 m³	4	24	31	5	0	1	1	8	6	20	1	4	32

Table 9
(continued)

CI-7206

	Station Number												
	21	22	25	26	27	28	29	30	32	33	35	36	37
Eukrohnia bathyantarctica	-	-	-	-	-	-	-	-	-	-	-	-	-
E. bathypelagica	-	-	-	-	-	5.9	-	-	-	-	-	5.3	-
E. fowleri	-	-	-	-	-	41.2	33.3	35.7	25.0	-	-	31.6	-
E. hamata	-	-	-	-	-	-	-	-	-	-	-	-	-
Krohnitta pacifica	25.0	-	-	-	-	-	-	-	-	-	-	-	-
K. subtilis	-	-	-	-	-	-	-	-	-	-	-	-	-
Pterosagitta draco	-	-	-	-	-	-	-	7.1	-	-	-	-	-
Sagitta bipunctata	-	-	-	-	-	-	-	-	-	6.9	-	-	-
S. decipiens	-	14.3	-	-	-	2.9	-	-	-	5.6	-	-	-
S. enflata	50.0	-	-	-	-	5.9	16.7	14.3	-	25.0	100.0	-	-
S. helenae	-	-	-	-	-	-	-	-	-	-	-	-	-
S. hexaptera	-	28.6	-	16.7	-	-	-	14.3	-	2.8	-	-	-
S. hispida	-	14.3	-	-	-	-	-	14.3	-	-	-	-	-
S. lyra	-	28.6	-	-	-	2.9	-	-	-	-	-	-	-
S. macrocephala	-	-	-	16.7	-	41.2	16.7	14.3	50.0	-	-	57.9	-
S. megalopthalma	25.0	-	-	-	-	-	-	-	-	-	-	-	-
S. serratodentata	-	14.3	100.0	66.7	-	-	33.3	-	-	59.7	-	5.3	-
S. tenuis	-	-	-	-	-	-	-	-	-	-	-	-	-
S. zetesios	-	-	-	-	-	-	-	-	25.0	-	-	-	-
Total Number per 1000 m³	4	7	3	12	0	34	6	14	4	72	3	19	0

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Table 10

Percentages of chaetognath species in samples collected during CI-7309.

CI-7309	Station Number					
	10	11	12	13	14	15
Eukrohnia fowleri	25.0	-	33.3	15.4	28.6	15.2
E. hamata	-	-	-	7.7	7.1	-
Krohnitta subtilis	-	-	-	7.7	-	-
Sagitta bipunctata	-	-	-	7.7	-	-
S. enflata	25.0	42.9	33.3	15.4	7.1	21.2
S. hexaptera	-	-	-	-	-	6.1
S. lyra	25.0	-	-	-	7.1	-
S. macrocephala	-	28.6	-	15.4	35.7	45.5
S. minima	-	-	-	-	-	6.1
S. serratodentata	25.0	28.6	33.3	30.8	14.3	6.1
Total Number per 1000 m³	8	7	6	26	28	33

Table 11

Percentages of chaetognath species in samples collected during CI-7317.

| CI-7317 | Station Number | | | | | | | | | |
	1	2	3	4	5	6	9	10	11	12
Eukrohnia bathypelagica	-	-	-	-	6.9	-	6.0	-	-	10.0
E. fowleri	-	-	-	-	13.8	-	17.9	14.3	33.3	40.0
E. hamata	-	-	2.3	-	6.9	-	29.8	14.3	-	10.0
Krohnitta subtilis	-	-	15.9	-	-	-	-	-	-	-
Pterosagitta draco	-	-	-	-	-	-	2.4	-	-	-
Sagitta decipiens	-	-	22.7	-	-	-	-	-	-	-
S. enflata	100.0	-	15.9	100.0	-	100.0	2.4	-	16.7	20.0
S. hexaptera	-	-	2.3	-	6.9	-	-	14.3	-	-
S. lyra	-	-	-	-	6.9	-	6.0	-	-	-
S. macrocephala	-	50.0	6.8	-	51.7	-	35.7	57.1	50.0	20.0
S. minima	-	-	2.3	-	-	-	-	-	-	-
S. serratodentata	-	50.0	31.8	-	6.9	-	-	-	-	-
Total Number per 1000 m^3	2	2	44	3	29	5	17	7	6	10

Table 12

Percentages of chaetognath species in samples collected during CI-7401.

CI-7401	Station Number														
	1	3	5	6	7	8	9	12	13	14	16	18	19	20	21
Eukrohnia bathypelagica	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
E. fowleri	33.3	-	16.7	36.8	-	25.0	-	52.6	100.0	-	20.0	-	-	50.0	-
E. hamata	-	-	-	-	-	-	-	-	-	-	20.0	-	-	-	-
Krohnitta subtilis	-	-	-	15.8	-	25.0	-	-	-	-	20.0	-	-	-	-
Sagitta sp.[6]	-	-	-	-	-	25.0	-	-	-	-	-	11.1	-	-	-
S. bipunctata	-	-	-	-	-	25.0	-	-	-	-	-	-	-	-	-
S. enflata	8.3	75.0	25.0	26.3	100.0	-	71.4	15.8	-	-	-	88.9	100.0	-	-
S. hexaptera	-	25.0	-	-	-	-	-	-	-	-	10.0	-	-	-	-
S. lyra	-	-	-	-	-	-	-	15.8	-	-	-	-	-	-	-
S. macrocephala	58.3	-	29.2	10.5	-	-	-	15.8	-	-	30.0	-	-	-	-
S. serratodentata	-	-	4.2	10.5	-	-	28.6	-	-	-	-	-	-	50.0	-
Total Number per 1000 m³	12	4	24	19	2	8	7	19	2	0	20	18	3	4	0

[6] Small unidentifiable specimens of *Sagitta*.

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below 600 m in the Straits could be explained in terms of the secondary circulation (sub- or supergeostrophy) postulated by Düing et al. (1977) and discussed earlier (Fig. 3). Downgliding of water along the edge of the thermal front could explain the presence of epipelagic species at depths of over 600 m. Since the downward movement during SWF (supergeostrophic condition) occurs along the upper edge of the front in the region of the 15°C isotherm, the animals collected below 600 m would have had to cross the front. This would appear a biological impossibility because the epipelagic chaetognath species found at this depth are passively carried by currents and do not perform extensive vertical migrations. Rather it seems more likely that these species might be advected downward along the lower edge of the front by a positive u-component (cross-stream flow to the east) during NWF (subgeostrophic condition).

That the animals tend to follow the isotherms is apparent from Owre's (1960) work in the Straits at two stations 10 and 40 miles east of Miami. When comparing the vertical distribution of species occurring at both locations, she found that the depth of the mean day or 50% level (depth above which 50% of an individual species are found) for all species was lower at the eastern station (Fig. 31). This, she thought, was probably the result of the steep downward slope of the isotherms from west to east. She noted that the mean temperatures at the 50% levels at the 40-mile station were warmer by 0.5°C - 5.6°C than those at the 10-mile sta-

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1·0   2·8   2·5

5·0   3·15   2·2

5·6

6·3   3·5

1·1   7·1   4·0   2·0

8·0

9·0   4·5

1·8

1·25   1·4   1·6
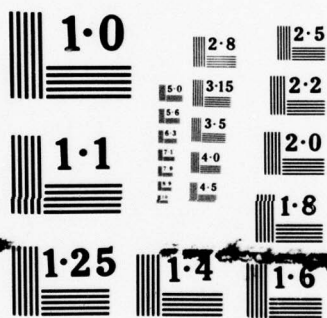
NATIONAL BUREAU OF STANDARDS
MICROCOPY RESOLUTION TEST CHART
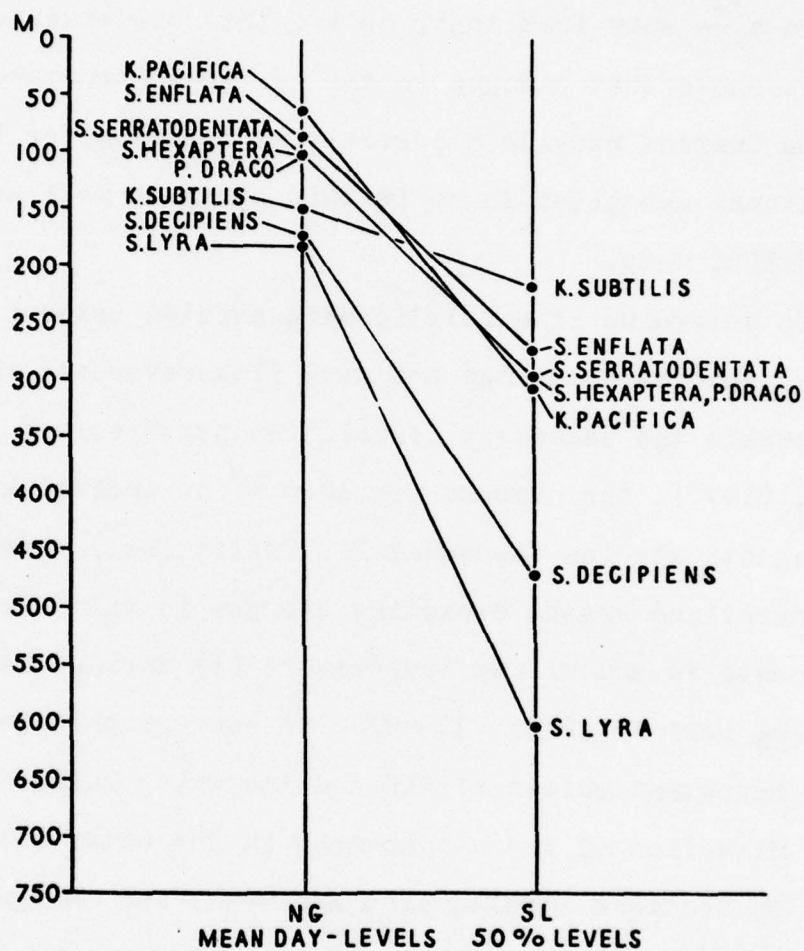
Figure 31

Comparison of depths of mean day levels of chaetognaths at
the 10-mile station (NG) with depths of 50% levels at the
40-mile station (SL) (from Owre, 1960).

tion and closer to the species optima than the colder tempera-
ture levels at the 10-mile station. "If this is so," she
stated "then some factor or combination of factors must be
forcing these species in the shallower water column on the
western side away from their optima into colder water." It
will be shown that changes in the vertical structure of the
Florida Current provide a possible explanation for the dis-
tributional anomalies found in this study as well as in
Owre's 1960 data.

To determine if a relationship existed between the
unusual species groupings and deep flow reversals which might
corroborate the secondary circulation hypothesized by Düing
et al. (1977), the numbers per 1000 m^3 of individual
chaetognath species (Appendix II, Tables 1-21) were plotted
on generalized graphs depicting changes in the u- and v-
components (u and v) and temperature (t) during the four
sampling periods (Figs. 32-42). On each graph, the shaded
areas represent pulses of SWF and the white background is
NWF. Direction of the u-component in the water column is
noted by sections labeled east and west, and change in tem-
perature is depicted by plots of variation in the depth of
the 10°C and 15°C isotherms. Black dots represent the level
of the deep plankton collections. Symbols (→←) on the
lower axis in graphs for CI-7309 (Figs. 34 and 38) indicate
profiles and samples taken out of the usual sampling sequence
(0000, 0600, 1200, 1800 hrs) at 2100 (P 3) and 1500 (P 7).
The generalized graphs for CI-7401 (Figs. 36 and 40) show

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deep plankton collections through Station 15. Species data,
however, are available for five additional stations (Table
12) during this survey. These data were not plotted due to
lack of corresponding physical data caused by malfunction of
the current meter. The following is apparent from the
figures:

Neritic species: The neritic species S. helenae,
S. hispida, and S. tenuis (Fig. 32) were rarely collected.
Each was found in very small numbers during only one sampling
period (CI-7206). S. helenae and S. tenuis were recorded
once, at 679 m and 691 m, respectively, during a transition
period between NWF and SWF and S. hispida twice, at the end
of the transition period (681 m) and during the following
pulse of SWF at 685 m. All were collected either midway
through (S. tenuis), at the end of (S. helenae and S. his-
pida), or immediately after (S. hispida), the rising and
broadening of the 10°C and 15°C isotherms typical of the
subgeostrophic condition. This suggests that the species
were advected downward along the lower edge of the thermal
front during NWF. They do not appear until the latter part
of the transition period or early SWF due to the lag between
the time they are advected downward and the time they reach
the sampling depth. The small numbers collected are probably
due to the coastal origin of the species. Their presence
below 600 m definitely indicates that a portion of the water
which moved downward originated in coastal areas.

Epipelagic oceanic species: Maximum numbers of the epi-

85
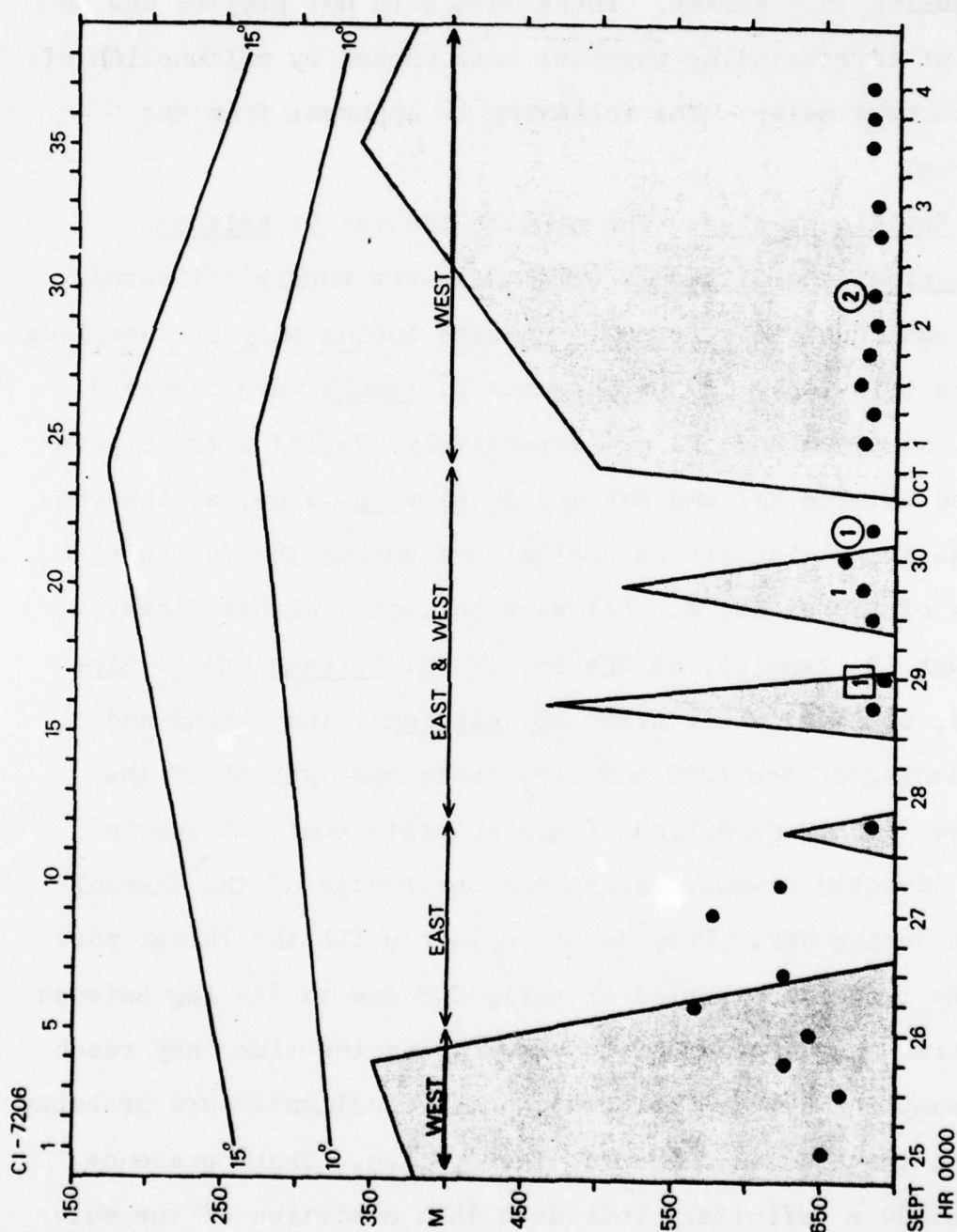
Figure 32

The occurrence of the neritic species Sagitta helenae,
S. hispida (○), and S. tenuis (□) in relation to changes
in u, v, and t during CI-7206.

pelagic oceanic species _Krohnitta_ _pacifica_, _Pterosagitta_
draco, _Sagitta_ _bipunctata_, _S_. _enflata_, _S_. _hexaptera_, _S_.
minima, and _S_. _serratodentata_ are usually found in the upper
100 m, with the exception of _S_. _hexaptera_ (0-200 m) (Michel
_et al_., 1976). _K_. _pacifica_, _P_. _draco_, _S_. _bipunctata_, and
_S_. _minima_ (Figs. 33-36) occurred infrequently, while _S_. _en_-
flata and _S_. _serratodentata_ (Figs. 37-40) were comparatively
common. _S_. _hexaptera_ (Figs. 37-40) was present in numbers
intermediate between the two groups. These findings agree
with the relative abundances of these species in the upper
layers of the Florida Current (Owre, 1960). Owre found
_S_. _enflata_ and _S_. _serratodentata_ to be the most abundant epi-
pelagic oceanic forms at two locations 10 and 40 miles east
of Miami which were sampled repeatedly in 1950-1952 (Table
13). On the basis of the total counts, 57.5% and 16.8% of
the oceanic epipelagic species reported at the 10- and 40-
mile stations were _S_. _enflata_ and 21.1% and 61.6%, respec-
tively, were _S_. _serratodentata_. These species were also most
abundant in the deep samples where 36.1% and 50.0% (CI-7206),
43.5% and 43.5% (CI-7309), 47.7% and 39.7% (CI-7317), and
73.3% and 8.3% (CI-7401) of the epipelagic oceanic species
collected were, respectively, _S_. _enflata_ and _S_. _serratoden_-
tata. The small percentage of _S_. _serratodentata_ found during
CI-7401 (8.3%) may result from the atypical current structure
observed during this time series (Figs. 21-24). The infre-
quently recorded species _K_. _pacifica_, _P_. _draco_, _S_. _bipunctata_,
and _S_. _minima_ each constituted less than 10% of the epipelagic

87
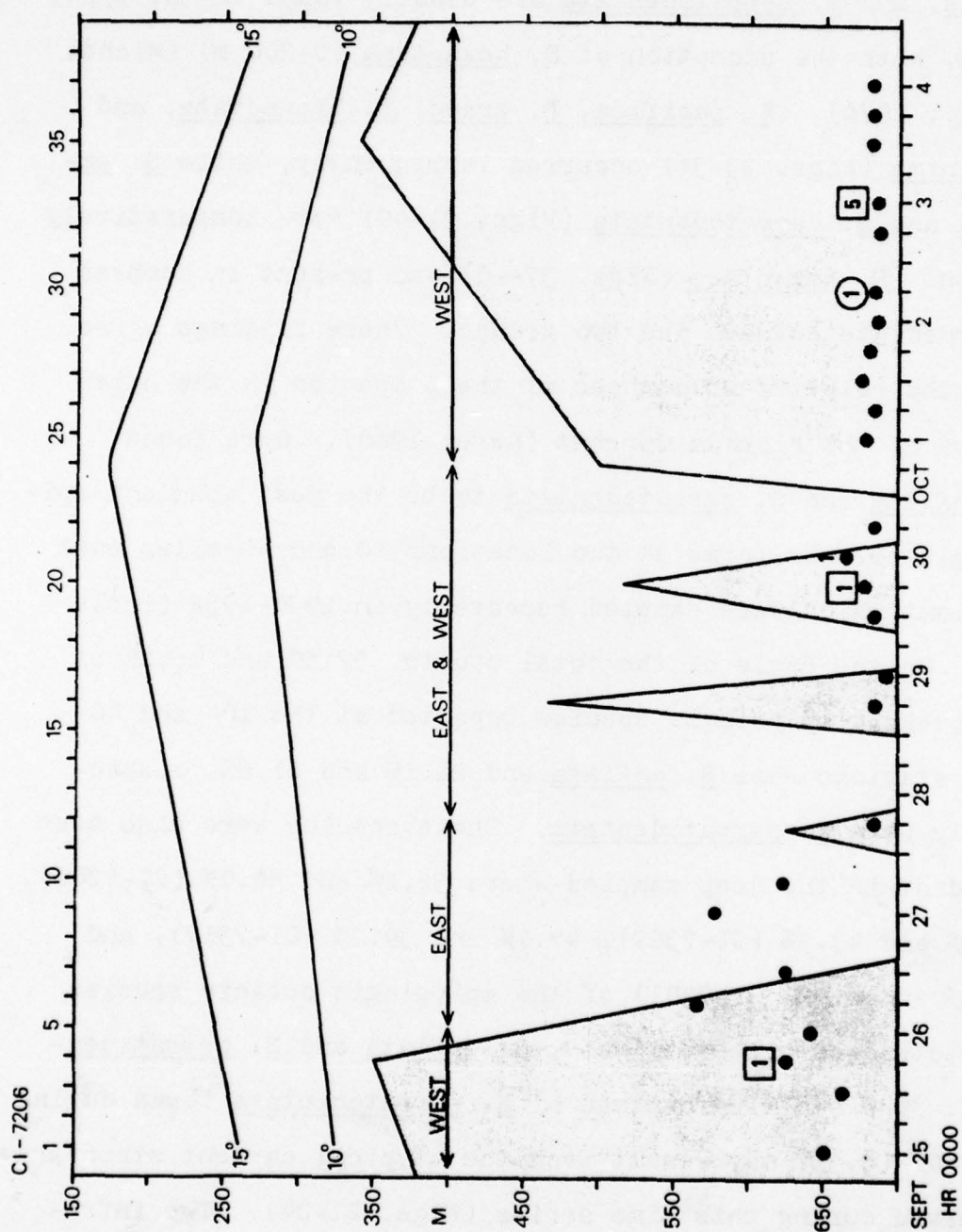
Figure 33

The occurrence of the oceanic epipelagic species Krohnitta pacifica, Pterosagitta draco (○), and Sagitta bipunctata (□) in relation to changes in u, v, and t during CI-7206.
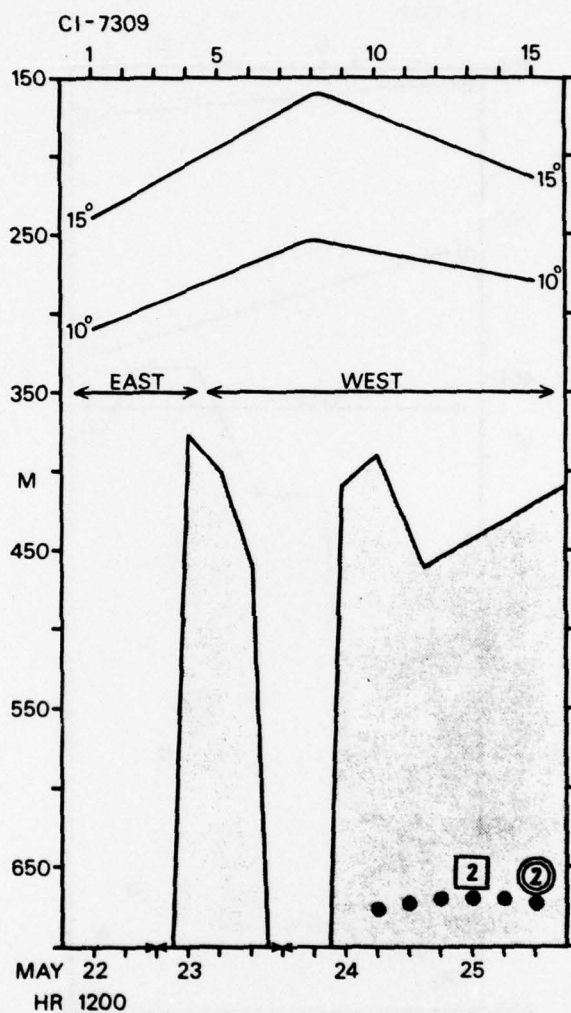
Figure 34

The occurrence of the oceanic epipelagic species <u>Sagitta</u>
<u>bipunctata</u> (□) and <u>S</u>. <u>minima</u> (◎) in relation to changes
in u, v, and t during CI-7309.
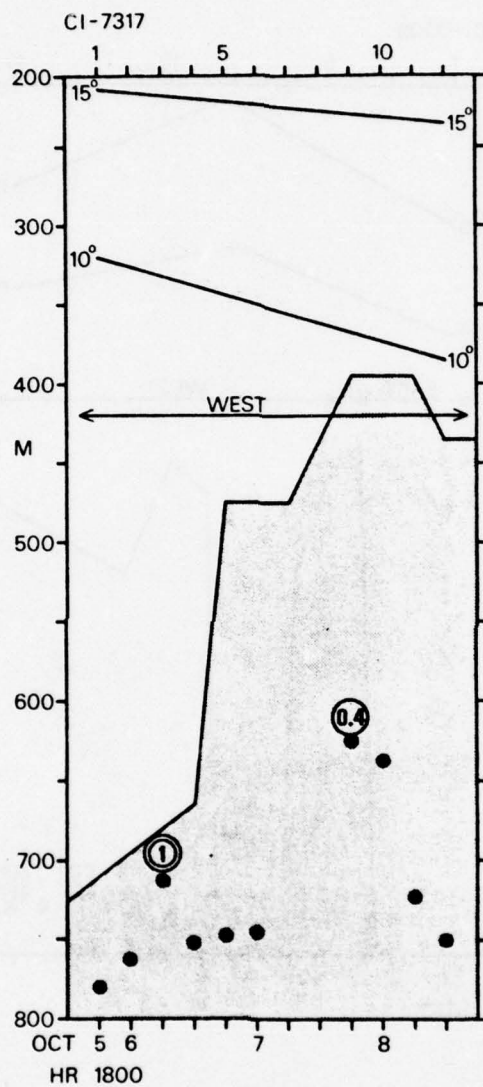
Figure 35

The occurrence of the oceanic epipelagic species _Ptero-sagitta_ _draco_ (O) and _Sagitta_ _minima_ (◎) in relation to changes in u, v, and t during CI-7317.
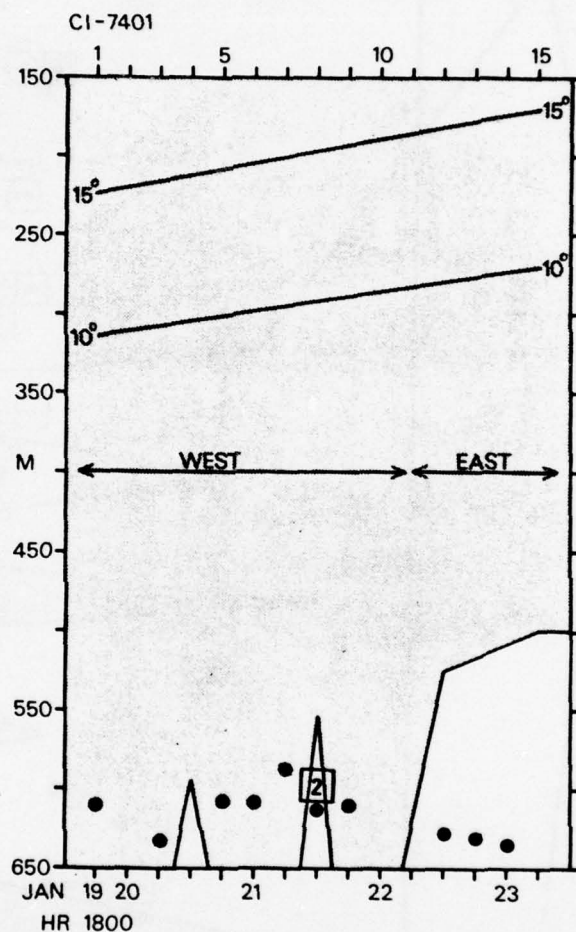
Figure 36

The occurrence of the oceanic epipelagic species <u>Sagitta</u>
<u>bipunctata</u> in relation to changes in u, v, and t during
CI-7401.
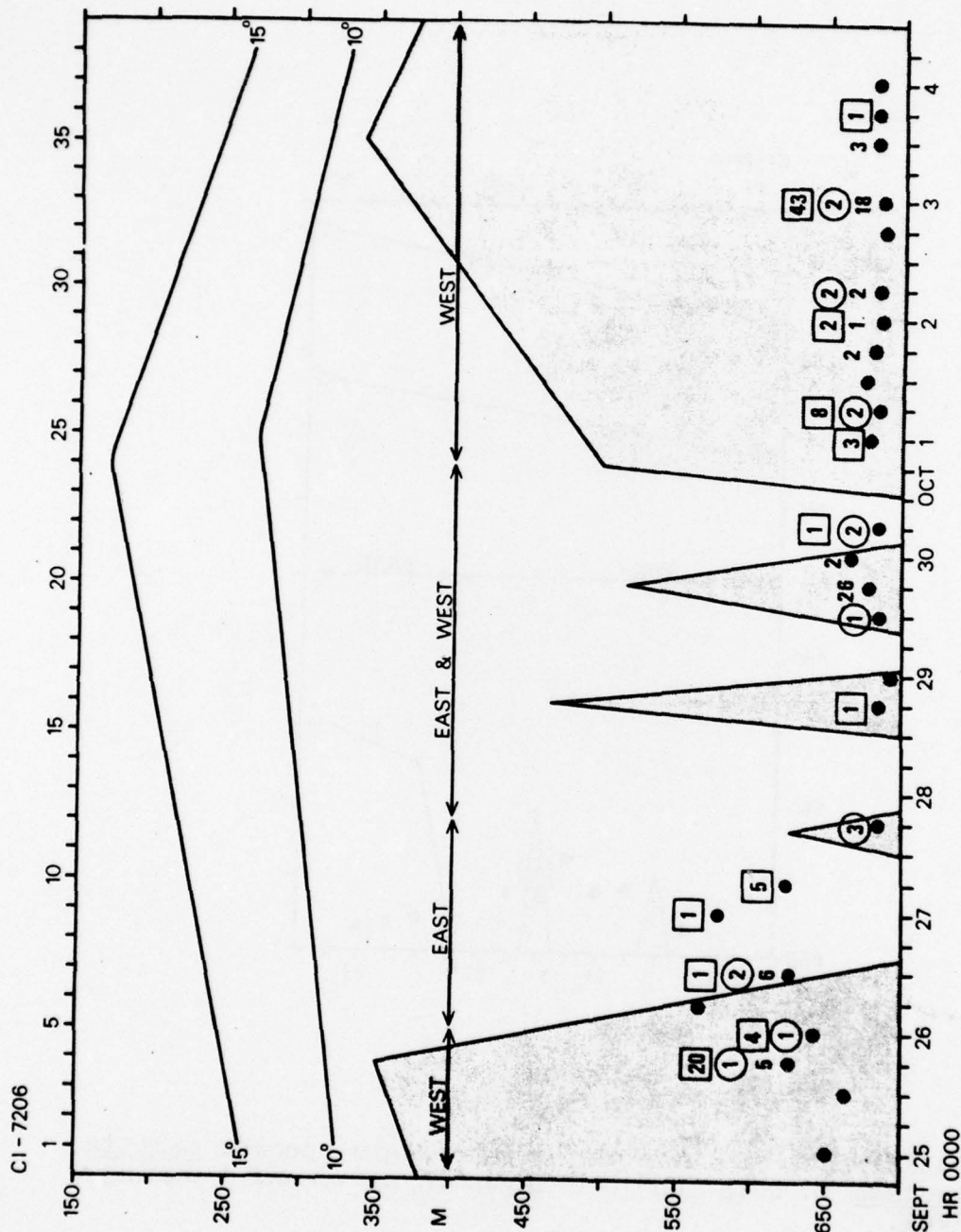
Figure 37

The occurrence of the oceanic epipelagic species Sagitta enflata, S. hexaptera (○), and S. serratodentata (□) in relation to changes in u, v, and t during CI-7206.

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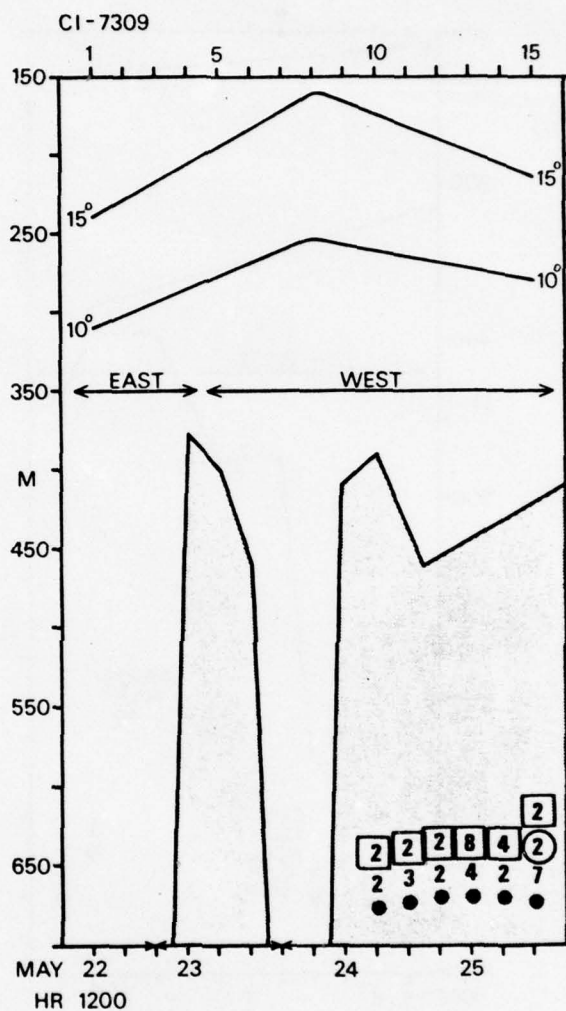
Figure 38

The occurrence of the oceanic epipelagic species <u>Sagitta</u>
<u>enflata</u>, <u>S</u>. <u>hexaptera</u> (◯), and <u>S</u>. <u>serratodentata</u> (☐) in
relation to changes in u, v, and t during CI-7309.

93
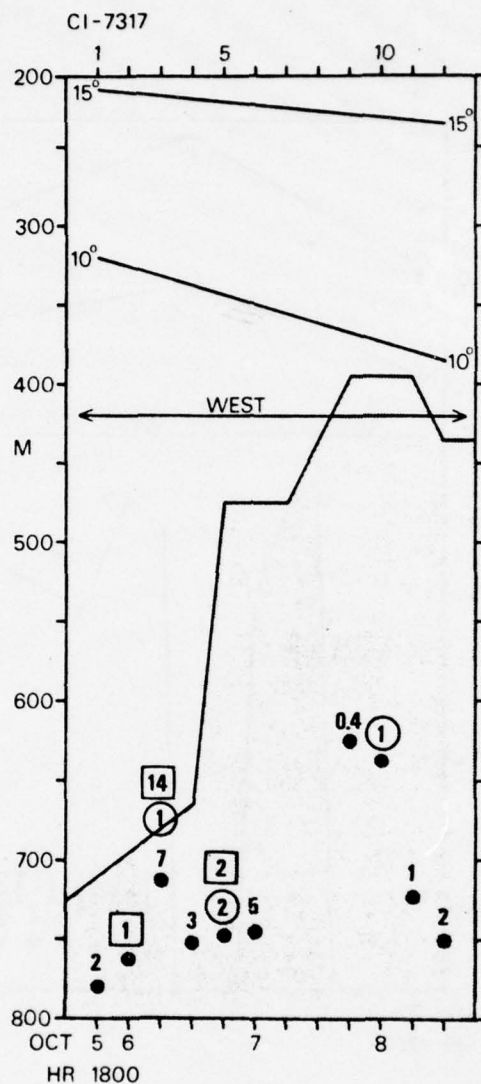
Figure 39

The occurrence of the oceanic epipelagic species <u>Sagitta</u> <u>enflata</u>, <u>S</u>. <u>hexaptera</u> (○), and <u>S</u>. <u>serratodentata</u> (□) in relation to changes in u, v, and t during CI-7317.
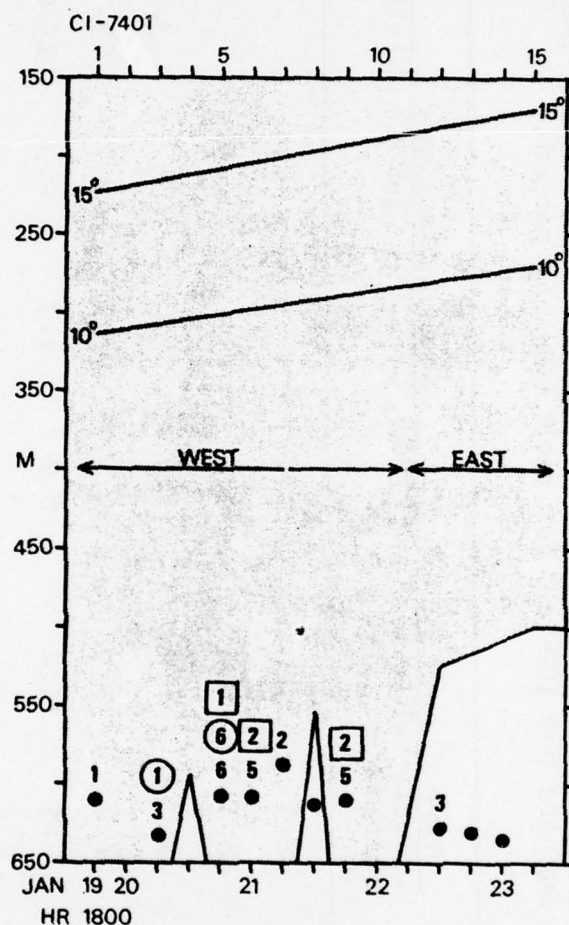
Figure 40

The occurrence of the oceanic epipelagic species <u>Sagitta</u>
<u>enflata</u>, <u>S</u>. <u>hexaptera</u> (○), and <u>S</u>. <u>serratodentata</u> (□) in
relation to changes in u, v, and t during CI-7401.

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Table 13

Relative percentages of oceanic epipelagic chaetognaths collected by Owre (1960) and in the deep collections made during CI-7206, CI-7309, CI-7317, and CI-7401. The 10-mile and 40-mile station data were computed from the total numbers of chaetognaths taken at 2 stations 10 and 40 miles east of Miami. Data for CI-7206, CI-7309, CI-7317, and CI-7401 are based on total numbers per 1000 m³ for each sampling period

Species	Owre (1960) 10-mile station	40-mile station	Deep Collections CI-7206	CI-7309	CI-7317	CI-7401
Krohnitta pacifica	2.5	6.0	0.6	-	-	-
Pterosagitta draco	6.5	8.4	0.6	-	0.9	-
Sagitta bipunctata	5.0	1.9	3.9	4.3	-	3.3
S. enflata	57.5	16.8	36.1	43.5	47.7	73.3
S. hexaptera	0.8	5.2	8.9	4.3	9.3	15.0
S. minima	6.6	0.1	-	4.3	2.3	-
S. serratodentata	21.1	61.6	50.0	43.5	39.7	8.3

forms in Owre's study. In the deep collections, each represented less than 5% of the total epipelagic species collected. The relationship between the relative abundances of these species in the upper and lower portions of the water column is significant since it supports the postulated contribution of shallow oceanic waters to the deep current. If the animals are being carried down locally, it would be expected that their proportions near bottom would be similar to those in the upper layers as is the case here.

The infrequently collected epipelagic species were most often found at the end of or immediately following the subgeostrophic condition indicated by the slope of the 10°C and 15°C isotherms. _K_. _pacifica_ and _S_. _bipunctata_ (Fig. 33) were collected during CI-7206 at the end of the transition period between NWF and SWF and at the end of a period of subgeostrophy (note slope of the isotherms in Fig. 33). _P_. _draco_, _S_. _bipunctata_, and _S_. _minima_ (Figs. 33-35) were all collected during periods of SWF, with the associated steepening of the isotherms, 12-48 hrs after a change from the subgeostrophic condition. _S_. _bipunctata_ (Fig. 36) was the only infrequently occurring epipelagic oceanic species collected during CI-7401. As discussed earlier, the vertical structure of the current during CI-7401 is atypical. On the basis of the isotherms alone, however, _S_. _bipunctata_ was found during a period of subgeostrophy. As in the case of the neritic species, the occurrence below 600 m of the infrequently collected epipelagic oceanic forms seems to indicate

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downward advection of the species along the lower edge of the thermal front. Their appearance at the end of the subgeostrophic period or, in the following pulse of SWF, is due to a time lag.

The two most common species S. enflata and S. serratodentata (Figs. 37-40) were collected throughout the four sampling periods. Both were found at the end of and following periods of subgeostrophy (Figs. 37-39). S. enflata was relatively rare in CI-7206, P 1-19 (Fig. 37), a period which, based on the end of a period of SWF at P 1-7 and the steepening of the 10°C and 15°C isotherms apparent at P 1, followed the supergeostrophic condition. In the same sampling period, S. serratodentata while present in P 4-10 was also relatively rare in P 11-19. Its presence in P 4-10 could be explained either by an earlier period of NWF and its associated condition of subgeostrophy occurring prior to the time series or by the fact that S. serratodentata, being one of the commoner species, is being carried back and forth by changes from NWF to SWF. It thus could seem to be present following supergeostrophy when in actuality it had been carried down during a previous period of NWF. Both species were found during CI-7401 (Fig. 40) but their distribution is difficult to interpret due to the unusual current patterns. S. hexaptera, the third most numerous species in the four sample sets (Figs. 37-40), showed a pattern of distribution similar to that of S. enflata and S. serratodentata.

The occurrence of the epipelagic oceanic species thus

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seems to support the hypothesis that water is being advected along the lower edge of the thermal front during NWF. It should be noted that although maximum numbers (>90% of the total catch) of oceanic epipelagic species are found in the upper 200 m, the total range of a given species may be much greater (Owre, 1960; Michel et al., 1976). The possibility of strays being an explanation for the anomalous species distributions recorded here, however, is not valid since the occurrence of epipelagic species in the deep samples shows a persistent pattern which can be directly correlated with changing physical conditions.

Meso- and meso-bathypelagic species: The mesopelagic species Krohnitta subtilis, Sagitta decipiens, S. lyra, and S. zetesios are usually found in maximum numbers from 200 to 500 m. Since certain species extend slightly higher or lower in the water column, however, 100-600 m has been chosen as the depth range for the mesopelagic after Michel et al. (1976). The mesopelagic species in the deep samples should be present more frequently and in larger numbers than the epipelagic forms whose presence can only be explained by downward advection. This is indeed the case as seen in Table 14 where Owre's (1960) data on the relative abundance of chaetognaths in the Florida Current off Miami is used to compare four of the epipelagic species collected with the mesopelagic forms. According to Owre, both sets of species are present in the water column less than 10% of the time, yet the mesopelagic forms, with the exception of S. zetesios,

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Table 14

Relative percentages of some of the chaetognath species collected by Owre (1960) at 2 stations in the Florida Current 10 and 40 miles east of Miami and the number of times and range in numbers per 1000 m³ of the same species collected in the present study.

Species		Owre (1960) Per cent at 10-mile station	Per cent at 40-mile station	Number of sampling periods during which collected	Deep Collections Number of times collected	Range in numbers per 1000 m³
Epipelagic:	Krohnitta pacifica	2.4	5.2	1	1	1
	Pterosagitta draco	6.2	7.3	2	2	0.4 - 1
	Sagitta bipunctata	4.7	1.6	3	5	1 - 5
	S. minima	6.3	0.1	2	2	1 - 2
Mesopelagic:	K. subtilis	0.7	3.1	4	5	2 - 7
	S. decipiens	1.8	6.5	2	6	1 - 10
	S. lyra	0.7	2.1	4	7	1 - 3
	S. zetesios	-	-	1	1	1
Meso-Bathypelagic:	Eukrohnia bathyantarctica	-	-	1	2	1 - 3
	E. bathypelagica	-	-	3	5	1 - 4
	E. hamata	<0.1	-	4	9	1 - 2
	E. fowleri	-	<0.1	4	27	1 - 14
	S. macrocephala	<0.1	<0.1	4	21	1 - 12

were found more often and in larger numbers in the deep
samples than the epipelagic species listed in Table 14.
S. zetesios, a cosmopolitan, mesopelagic form (Alvariño,
1965), is a new record for the Straits and may be rare in
the area.

The meso-bathypelagic species Eukrohnia bathyantarctica,
E. bathypelagica, E. fowleri, E. hamata, and S. macrocephala
are typically found at depths greater than 500-600 m. The
net was fished in the meso-bathypelagic zone, thus the pre-
sence of these species in the samples is not unusual. As
expected, they were generally collected more often and in
larger numbers than the epi- and mesopelagic species (Table
14). E. bathyantarctica and E. bathypelagica are exceptions
but, as in the case of S. zetesios, these species are new
records for the area and may be rare in the Straits.

While the distribution patterns of the epipelagic
species seem to be directly related to flow reversals and
associated changes in thermal structure, the meso- and meso-
bathypelagic species are more randomly distributed, which
is to be expected since they are normally found at 600 m.
For example, the neritic and infrequently occurring oceanic
epipelagic species collected during CI-7206 (Figs. 32-40)
were, with one exception, found exclusively at the end of
a transition between NWF and SWF or during the following
pulse of SWF. Since they appeared at the end of and subse-
quent to a period of subgeostrophy, their presence could be
explained by downgliding along the lower edge of the thermal

front. The mesopelagic species and the rare meso-bathy-
pelagic species E. bathyantarctica and E. bathypelagica
were collected relatively infrequently (Table 14) but were
not restricted to the same portion of the time series as
the epipelagic species. For example, during CI-7206 (Fig.
41), K. subtilis was collected in NWF immediately after the
supergeostrophic condition, S. decipiens during both pulses
of SWF and the transition period, and S. lyra during the
transition and second pulse of SWF. The most common meso-
bathypelagic species were found throughout the time series
with no apparent correlation with reversals. For example,
S. macrocephala (Fig. 42) was routinely collected during
CI-7206 in NWF and SWF and their corresponding conditions of
sub- and supergeostrophy, while S. enflata and S. serrato-
dentata (Fig. 37), collected during the same period, seemed
to vary directly with changes in vertical structure.

It thus appears that the unusual combinations of epi-
pelagic neritic and oceanic chaetognaths with meso- and meso-
bathypelagic forms below 600 m in the Straits provide direct
evidence for the hypothetical subgeostrophic condition postu-
lated by Düing et al. (1977), i.e., downward movement of
shallow water along the lower edge of the thermal front
roughly delimited by the 10°C and 15°C isotherms by a posi-
tive u-component during NWF. The secondary circulation is
probably not the only mechanism for advecting epipelagic
species downwards. Since it represents subtle vertical
circulation occurring perpendicular to the fast-moving Florida

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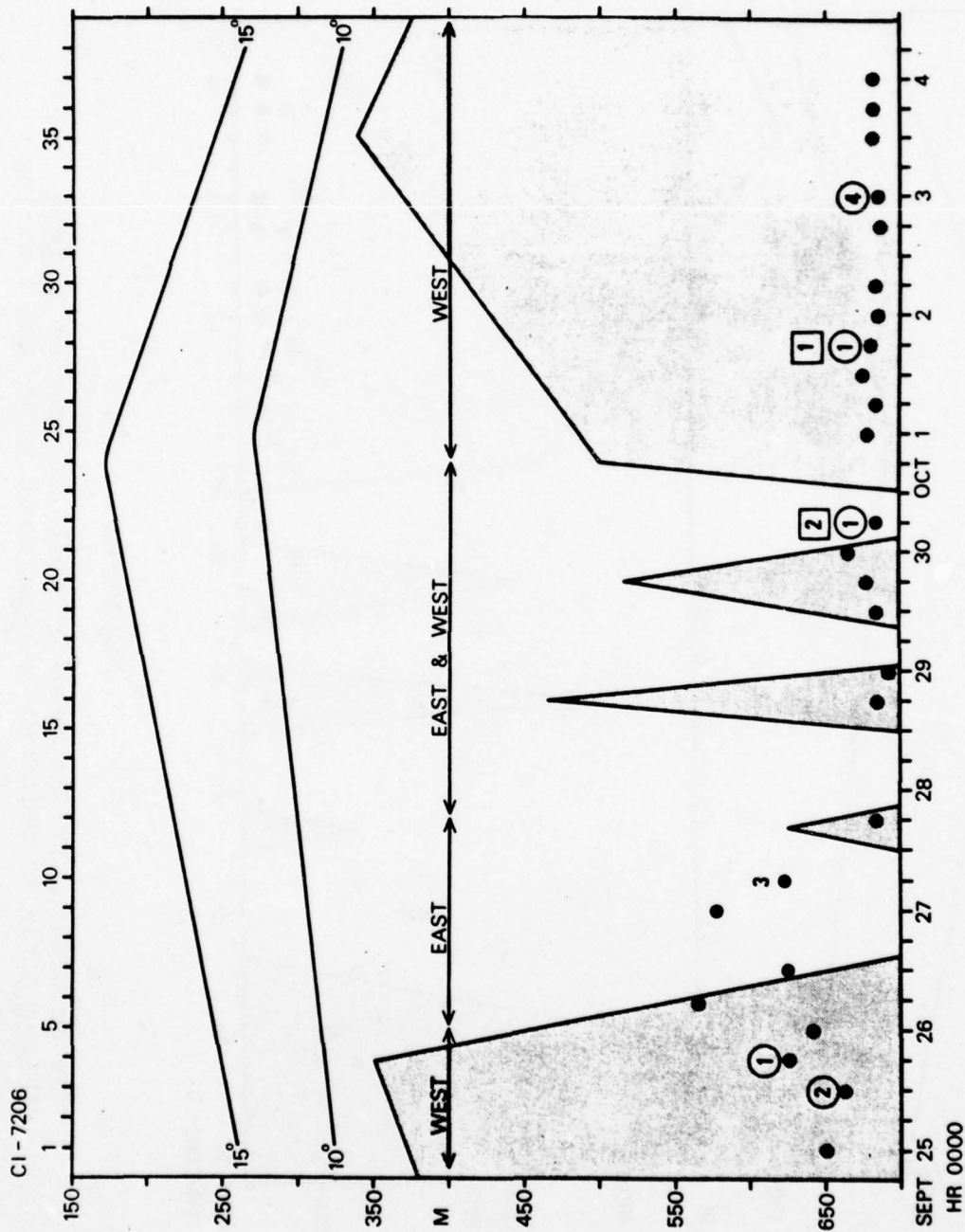
Figure 41

The occurrence of the mesopelagic species Krohnitta subtilis, Sagitta decipiens (O), and S. lyra (□) in relation to changes in u, v, and t during CI-7206.
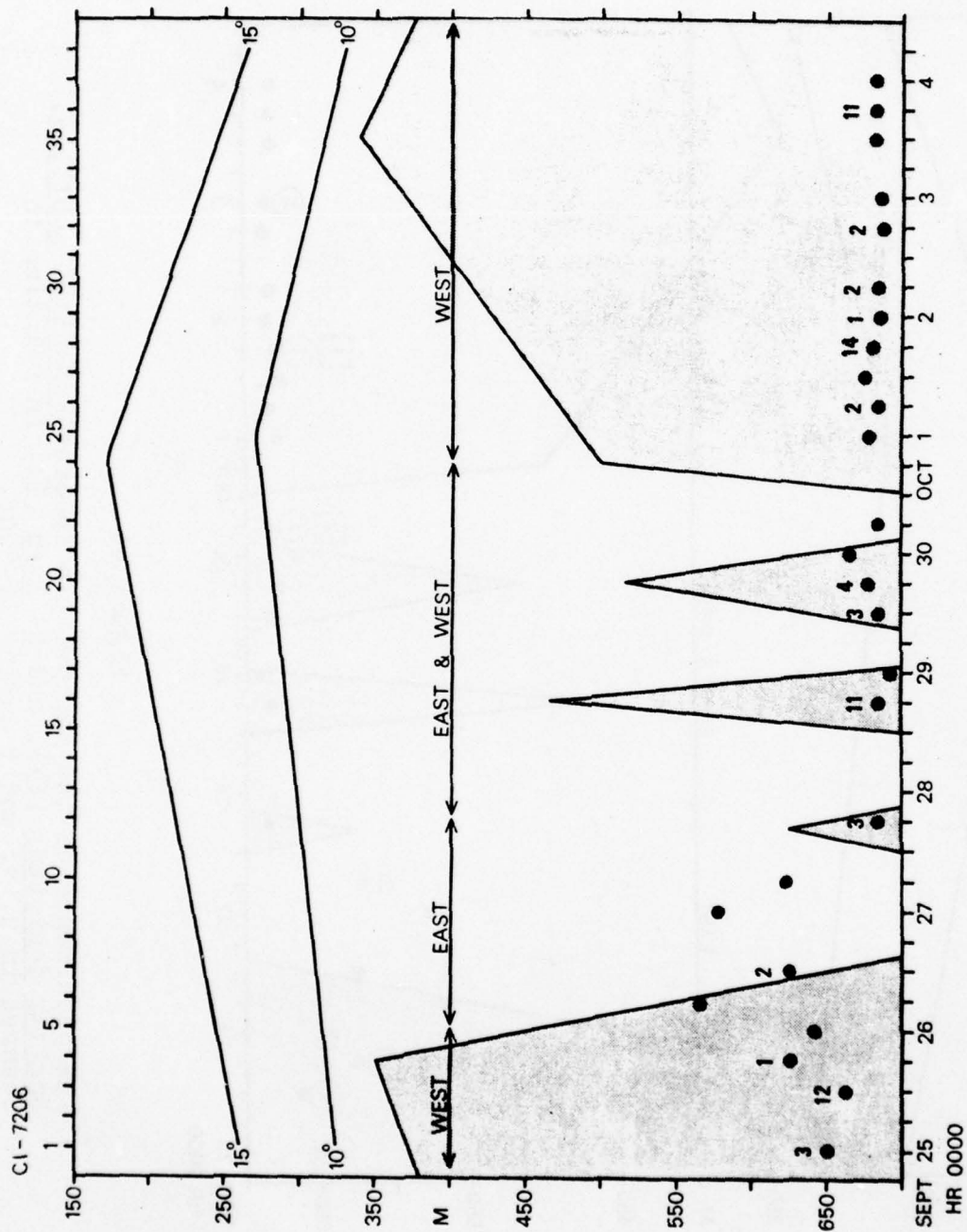
Figure 42

The occurrence of the meso-bathypelagic species *Sagitta macrocephala* in relation to changes in u, v, and t during CI-7206.

Current, it is likely that it operates in combination with larger-scale upwelling and downwelling associated with continental shelf waves.

The unusual species groupings described above indicate the downward movement of inshore and oceanic surface waters associated with deep flow reversals. Determining the origin of the water, however, requires further analysis. The relative proportions of certain species in the deep samples may provide a clue. The proportions of oceanic epipelagic species compare favorably with the known relative abundances of the same epipelagic species in the upper layers of the Florida Current off Miami (Table 13). This suggests that at least part of the water advected downward is of local origin. Certain species collected during SWF, however, indicate a contribution from coastal and oceanic areas to the north. Sagitta helenae and S. hispida are normally found in the shallow waters of the Gulf of Mexico as well as from eastern Florida to Delaware (Pierce, 1951, 1953, 1958; Deevey,1960). Owre (1960), confronted with the discovery of both species in relatively low numbers in the Florida Current off Miami, theorized that they were carried from the eastern Gulf of Mexico via coastal eddies and currents into the Florida Straits. In her study, both species, with one exception at 685 m, were found only in the upper 200 m while here they were collected below 600 m in pulses of SWF. The eurythermal and euryhaline coastal species S. tenuis is abundant in many localities from Delaware to Brazil but is not found in the

coastal waters of southeastern Florida (Pierce and Wass, 1962; Owre and Foyo, 1972). Sexually mature S. tenuis, however, occurred in one of the deep samples (Fig. 32). This indicates that coastal water originating north of Miami was present in the Straits off Miami during a pulse of SWF. Michel et al. (1976) suggested that S. megalopthalma and Eukrohnia hamata, both rare in the Caribbean and collected during SWF in the present study, may be indicators of waters from the North Atlantic. The recently described S. megalopthalma (Dallot and Ducret, 1969) has been reported in limited numbers at both epi- and mesopelagic levels in the Mediterranean, Gulf of Guinea, and Caribbean (Dallot and Ducret, 1969; Furnestin, 1970; Michel et al., 1976). Its presence in the Caribbean has been linked to inflow from the North Atlantic through the Windward Passage (Michel et al., 1976). It is possible that its presence off Miami represents a contribution of North Atlantic waters.

The known distribution of E. hamata provides strong evidence for the presence of Atlantic waters originating in the north. This species is a classical example of bipolar distribution with tropical submergence, being epipelagic in the Arctic and Antarctic and meso- to bathypelagic in tropical and equatorial regions (David, 1958; Alvariño, 1965). It has been reported as rare in the Caribbean, Gulf of Mexico, and, prior to this study, the Florida Straits, having been recorded in only three samples from the Caribbean (Colman, 1959; Michel et al., 1976), one from the Gulf of Mexico

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(Pierce, 1954) and in two samples from the Florida Straits
(Owre, 1960). In the western North Atlantic off the north-
eastern continental United States and Canada, it is much
more abundant. Grice and Hart (1962) in a study of the epi-
zooplankton between New York and Bermuda reported it in slope
waters. Due to its absence in warm and shelf waters and its
frequent occurrence in the deeper waters in the area of New-
foundland and Nova Scotia (Huntsman, 1919) and in the Gulf
of Maine (Bigelow, 1926; Redfield and Beale, 1940), they
considered it a good indicator of "cold waters in general,
and in the present area [off the northeastern United States]
slope waters in particular." Bigelow and Sears (1939) found
stray specimens in the outer neritic waters of the same area.
Pierce (1953, 1958), Bumpus and Pierce (1955), and Pierce
and Wass (1962) did not find it in shelf, slope, and shallow
Florida Current waters between Cape Hatteras and south
Florida, although Colman (1959) reported it as the dominant
species in a vertical tow from 750 m at a station 60 miles
northeast of Cape Hatteras. E. hamata was collected in
pulses of SWF a total of nine times during the four sampling
periods in numbers from 1-5 per 1000 m^3 (Appendix II, Table
4). In view of its scarcity in the Caribbean and Gulf of
Mexico, absence between Cape Hatteras and Florida, and rela-
tive abundance in slope waters and deeper regions to the
north, the appearance of this species at 600 m in the Florida
Straits during SWF suggests a contribution of northern oceanic
water. Perhaps its occurrence in the Straits is related to

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the proposed presence of Subarctic Water discussed earlier
in the Water Mass section.

Thus, the relative proportions of epipelagic species
found below 600 m and the presence of certain species as
S. tenuis and E. hamata and perhaps S. hispida, S. helenae,
and S. megalopthalma in samples collected during SWF suggest
that deep water in the Straits consists of a mixture of
coastal, shallow oceanic, and deep oceanic waters from both
local and northern regions.

Euthecosomata

Euthecosomatous[7] pteropods are widely distributed and
abundant in the world oceans. Depending on their distribu-
tion patterns, they are classified as Arctic, subpolar or
boreal, subtropical, and tropical (Meisenheimer, 1905, 1906;
Tesch, 1946; Chen and 3ê, 1964; Myers, 1968; Chen and Hill-
man, 1970; Austin, 1971; Haagensen, 1976). The bathymetric
distribution of the individual species is not as clearly
defined as that of the chaetognaths. Most species are
limited to the upper 200 m; a few are bathypelagic, and others
undergo diurnal migrations between the epipelagic and meso-
pelagic regions. However, as in the case of the chaeto-
gnaths, the distribution of many of the euthecosomes collected
in the deep samples varies from known patterns and thus
provides information on the changing vertical structure of

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[7]The terms "euthecosome" and "thecosome" are used
throughout this section. The Euthecosomata are a suborder of
the Order Thecosomata, Class Gastropoda, Phylum Mollusca.

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the Florida Current.

Fourteen species, one subspecies and nine formae, repre-
senting seven genera, were identified from the samples.
These are:

> Cavolinia longirostris (Blainville, 1821)
>
> C. longirostris f. longirostris (Blainville, 1821)
>
> C. longirostris f. strangulata (Deshayes, 1823)
>
> C. tridentata f. bermudensis van der Spoel, 1974
>
> C. uncinata uncinata f. uncinata (Rang, 1829)
>
> Clio pyramidata f. lanceolata (Lesueur, 1813)
>
> Creseis acicula (Rang, 1828)
>
> C. acicula f. acicula (Rang, 1828)
>
> C. virgula (Rang, 1828)
>
> C. virgula f. conica Eschscholtz, 1829
>
> C. virgula f. virgula (Rang, 1828)
>
> Cuvierina columnella (Rang, 1827)
>
> C. columnella f. atlantica van der Spoel, 1970
>
> Diacria trispinosa (Blainville, 1821)
>
> D. quadridentata (Blainville, 1821)
>
> Limacina bulimoides (d'Orbigny, 1836)
>
> L. inflata (d'Orbigny, 1836)
>
> L. lesueuri (d'Orbigny, 1836)
>
> L. trochiformis (d'Orbigny, 1836)
>
> Styliola subula (Quoy and Gaimard, 1827)

At the species level, all have been reported from the Florida
Straits, Caribbean, Gulf of Mexico, and the North Atlantic off
the continental United States (Table 15). At the infraspecific

Table 15

Previous records from the Caribbean, Gulf of Mexico, Florida Straits, and the North Atlantic off the continental United States of euthecosome species reported in this study. Additional records of Atlantic distribution have been summarized by Haagensen (1976), van der Spoel (1967, 1976), and Bé and Gilmer (1977).

Species	Caribbean[8]	Gulf of Mexico[9]	Florida Straits[10]	North Atlantic off continental United States[11]
Cavolinia longirostris	+	+	+	+
C. longirostris f. longirostris	+	-	-	-
C. longirostris f. strangulata	+	-	-	-
C. tridentata	+	+	+	+
C. tridentata f. bermudensis	+	+	+	+
C. uncinata	+	+	+	+
C. uncinata uncinata f. uncinata	+	-	-	-
Clio pyramidata	+	+	+	+

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Table 15
(continued)

Species	Caribbean[8]	Gulf of Mexico[9]	Florida Straits[10]	North Atlantic off continental United States[11]
C. pyramidata f. lanceolata	+	-	-	+
Creseis acicula	+	+	+	+
C. acicula f. acicula	+	+	-	-
C. virgula	+	+	+	+
C. virgula f. conica	+	+	+	+
C. virgula f. virgula	+	+	+	+
Cuvierina columnella	+	+	+	+
C. columnella f. atlantica	+	-	-	+
Diacria trispinosa	+	+	+	+
D. quadridentata	+	+	+	+
Limacina bulimoides	+	+	+	+

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Table 15
(continued)

Species	Caribbean[8]	Gulf of Mexico[9]	Florida Straits[10]	North Atlantic off continental United States[11]
L. inflata	+	+	+	+
L. lesueuri	+	+	+	+
L. trochiformis	+	+	+	+
Styliola subula	+	+	+	+

[8]Dautzenberg (1900); Dall and Simpson (1901); Meisenheimer (1905); Issel (1913); Tesch (1946); Suárez-Caabro (1959); Legaré (1961); Zoppi (1961); Cervignón and Marcano (1965); Lewis and Fish (1969); Troost and van der Spoel (1972); van der Spoel (1974); Wells (1975, 1976 a,b); Haagensen (1976).

[9]Dall (1889); Meisenheimer (1905); Furkerrroad (1933); Johnson (1934); Reed (1941); Tesch (1946); Moore (1958, 1961); Kornicker (1959); Hutton (1960); Parker (1960); Merrill (1963); Rodriguez (1965); Hopkins (1966); Hughes (1968); Austin (1971); Williams (1972); van der Spoel (1974).

[10]Dall (1889); Meisenheimer (1905); Tesch (1946); Moore et al. (1953); Wormelle (1962); Austin (1971); Gilmer (1974); van der Spoel (1974).

[11]Verrill (1880, 1882, 1884, 1885); Bush (1885, 1893); Dall (1889); Peck (1893); Meisenheimer (1905); Bigelow (1915, 1917, 1926); Johnson (1915, 1934); Bigelow and Sears (1939); Tesch (1946); Moore (1949); Deevey (1952 a,b, 1960, 1971); Chen (1962); Grice and Hart (1962); Chen and Bé (1964); Myers (1968); Chen and Hillman (1970); Deevey and Brooks (1971); van der Spoel (1973, 1974); Panhorst and van der Spoel (1974).

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level, however, little distributional information is available. The formae of Creseis virgula, f. conica and f. virgula, have been identified by a number of workers in the areas summarized in Table 15, but, with the exception of the extensive study of Haagensen (1976) in the Caribbean, and isolated reports by Burkenroad (1933), van der Spoel (1973, 1974), and Panhorst and van der Spoel (1974), collections in the Caribbean, Gulf of Mexico, Florida Straits, and northwest Atlantic have been identified only to species.

The species collected in the deep samples are tropical or subtropical forms whose vertical distributions have been studied by a number of investigators, including Haagensen (1976) in the Caribbean and Myers (1968) in the Cape Hatteras region. Both used opening-closing nets. Haagensen found that 96.7% of the total catch was collected in the upper 200 m and 99.8% in the upper 500 m. Myers also observed that most thecosomes occurred in the upper 200 m, with greatest concentrations between 0 and 60 m. On the basis of these data alone, the presence of euthecosomes at 600 m in the Florida Straits would be anomalous. However, although euthecosomes occur predominantly in the upper 200 m, some species undergo diurnal migrations from the epipelagic to the mesopelagic zone. The presence of a species at 600 m might be unusual or expected, depending on its migratory habits. Thus, in order to evaluate the deep distribution of euthecosomes in relation to flow reversals, the patterns of vertical migration reported for species identified in the

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deep samples must be considered. Using past data, euthecosomes have been classified as non-migratory or feebly migratory species (_Cavolinia longirostris_, _Creseis acicula_, _C. virgula_ f. _conica_, _C. virgula_ f. _virgula_, and _Limacina trochiformis_), limited primarily to the upper 100 m, and strongly migratory species (_Clio pyramidata_, _Cuvierina columnella_, _Limacina bulimoides_, _L. inflata_, _L. lesueuri_, and _Styliola subula_), living in the mesopelagic zone (100-600 m) during the day and in the upper epipelagic at night (Table 16). The difference in vertical distribution patterns of the non- or feeble migrators and the strong migrators is evident from individual species ranges and average depths reported by Myers (1968) and Haagensen (1976) (Table 17). _Cavolinia tridentata_, _C. uncinata_, _Diacria trispinosa_, and _D. quadridentata_ were not included in Table 16 owing to insufficient data in the literature (_C. tridentata_ and _C. uncinata_) or conflicting reports on diurnal migration patterns (_D. trispinosa_ and _D. quadridentata_). For example (Table 17), _C. tridentata_ and _C. uncinata_ have historically been collected in numbers too small to evaluate their vertical distribution patterns. _D. quadridentata_ and _D. trispinosa_ have been collected in larger numbers but, in the western North Atlantic and Caribbean, published reports on their diurnal vertical movements vary. Haagensen (1976) reported a vertical migration pattern for _D. quadridentata_ intermediate between the non- or feeble migrators and the strong migrators, while Myers (1968) found no evidence for migration in the Hatteras

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Table 16

Classification of selected euthecosome species collected
during CI-7206, CI-7309, CI-7317, and CI-7401 as non- or
feebly migratory species or strongly migratory species on
the basis of studies by Moore (1949), Chen (1962), Wormelle
(1962), Chen and Bế (1964), Myers (1968), van der Spoel
(1973), Panhorst and van der Spoel (1974), and Haagensen
(1976) in the Caribbean, Florida Straits, and North Atlantic
off the continental United States.

Non-migratory or feebly
    migratory species
    limited primarily to
    the upper 100 m.

Cavolinia longirostris
Creseis acicula
C. virgula f. _conica_
C. virgula f. _virgula_
Limacina trochiformis

Strongly migratory species
    living primarily in the
    mesopelagic zone (100-
    600 m) during the day
    and in the upper epi-
    pelagic zone at night.

Clio pyramidata
Cuvierina columnella
Limacina bulimoides
L. inflata
L. lesueuri
Styliola subula

Table 17

Diurnal migration patterns of euthecosome species discussed in this study as reported by Haagensen (1976) in the Caribbean, Wormelle (1962) at 2 stations in the Florida Straits 10 and 40 miles east of Miami, and Myers (1968) in the Cape Hatteras region. MDL and MNL represent mean day and night levels (depths above which 50% of an individual species occurred during the day or night).

| Species | Haagensen (1976) Caribbean | | | | Wormelle (1962) Florida Straits | | | | Myers (1968) Cape Hatteras | |
| | Adults | | Juveniles | | 10-mile station | | 40-mile station | | | |
	Day	Night	Day	Night	MDL	MNL	MDL	MNL	Day	Night
Non-migratory or feebly migratory species:										
Cavolinia longirostris	0-62 m	0-50 m (.5c)	0-275 m (50)	0-1000 m (34)	215 m	76 m	118 m	42 m	25-75 m	0-75 m
Creseis acicula	68.9% at surface 96.5% in upper 65	79.7% at surface 98.6% in upper 52	41.2% at surface 95.5% in upper 90	77.6% at surface 99.9% in upper 75	157	52	185	200	0-75, maximum at 50	0-75, maximum at surface at sunrise and sunset
C. virgula f. conica	54.8% at surface all in upper 80	2.5% at surface all in upper 80	4.0% at surface all in upper 80	1.1% at surface all in upper 80	206[14]	98	319	167	0-75, concentrated in upper 50, no discernible migratory pattern	
C. virgula f. virgula	42.9% at surface all in upper 80	39.7% at surface all in upper 80	all in upper 80	all in upper 80	–	–	–	–	–	13
Limacina trochiformis	(50)	(34)	(35)	(34)	165	99	88	120	0-100, no clear migratory pattern	
Strongly migratory species:										
Clio pyramidata	–	13	224-531 (445)	65 (65)	–	–	–	13	absent	at all sample depths (0-150) just after sunset
Cuvierina columnella	224-344	upper 65	30-290 (53)	upper 75 (48)	collected very few in day, higher numbers at night; maximum at 50-250	–	–	–	absent	adults in surface waters only at night

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Table 12
(continued)

Species	Haagensen (1976) Caribbean				Wormelle (1962) Florida Straits				Myers (1968) Cape Hatteras	
	Adults		Juveniles		10-mile station		40-mile station			
	Day	Night	Day	Night	MDL	MNL	MDL	MNL	Day	Night
Limacina bulimoides	below 225	upper 53	-	-[13]	maximum at 120[13]		-	-[13]	absent from upper 100	at surface at sunset
L. inflata	(265)	(sfc)	upper 90	upper 90	236	232	218	163	adults below 90, juvenile maximum at 50	adult maximum 25-50, juvenile maximum at surface
L. lecueuri	224-274 (265)	upper 65 (31)	224-274 (30)	upper 65 (48)	103	85	289	398	below 150	0-75
Styliola subula	(265)	(48)	(30)	(65)	234	81	504	171	below 75	0-75, maximum at surface
Others:										
Cavolinia tridentata	-	-	-	-[13]	-	-	-	-[13]	-	[13]
C. uncinata	59-250	0-132	-	-[13]	-	-	-	-[13]	-	[13]
Diacria trispinosa	55-90 and 225-344 (250)	45-81 (50)	0-524 (250)	0-590 (56)	219	187	-	-[13]	juveniles in upper 125	few adults, all below 50
D. quadridentata	30-125 (50)	0-65 (0)	50-261 (160)	0-258 (65)	169	134	214	163	no evidence of migration 60	no evidence of migration, species from 20-60
Sampling Range (m)	0-7500				0-700				0-150	
Gear Used	Opening-Closing Modified Discovery Net				Closing Modified Discovery Net				Clarke-Bumpus Sampler	

[12] Numbers in parentheses are average day and night depths. These correspond to Wormelle's MDL and MNL (depths above which 50% of an individual species occurred during the day or night).

[13] Migration patterns could not be evaluated due to small numbers collected.

[14] Wormelle did not distinguish infraspecific forms. Depths are for C. virgula.

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area. $\underline{D}$. $\underline{trispinosa}$ definitely undergoes vertical migration,
but on the basis of Haagensen's (1976) and Myers (1968)
works and a study by Panhorst and van der Spoel (1974), it
also would be placed in a category between the non- and
strongly migratory euthecosomes. These four species have
thus been grouped in a general category called Others (Table
17).

The presence below 600 m of the non- or feebly migrating
species typical of the upper 100 m, $\underline{Cavolinia}$ $\underline{longirostris}$,
$\underline{Creseis}$ $\underline{acicula}$, $\underline{C}$. $\underline{virgula}$ f. $\underline{conica}$, $\underline{C}$. $\underline{virgula}$ f. $\underline{virgula}$,
and $\underline{Limacina}$ $\underline{trochiformis}$, in periods of SWF during all four
surveys (Tables 18-21), is clearly a distributional anomaly.
As in the case of the chaetognaths, these occurrences during
deep flow reversals indicate that the current near bottom
contains a combination of deep Atlantic water and shallow
oceanic water.

The work of Wormelle (1962) at two stations in the
Florida Current, 10 and 40 miles east of Miami, provides
additional support for this premise. She also collected
$\underline{C}$. $\underline{longirostris}$, $\underline{C}$. $\underline{acicula}$, $\underline{C}$. $\underline{virgula}$, and $\underline{L}$. $\underline{trochiformis}$
at depths of 600-700 m. In the same study, Wormelle studied
diurnal migration by computing the mean day and mean night
levels (depth above which 50% of the individuals collected
occurred) for individual species. In many cases, her results
differ from those obtained in other studies. For example,
her data (Table 17) suggest that $\underline{C}$. $\underline{virgula}$ has a large
vertical range and undergoes strong diurnal migrations. She

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Table 18

Percentages of euthecosome species in samples collected during CI-7206.

CI-7206	Station Number												
	1	3	4	5	6	7	9	10	12	16	17	19	20
Cavolinia longirostris	-	-	-	-	-	-	-	-	-	-	-	-	-
C. tridentata	-	-	-	-	-	-	-	-	-	-	-	-	-
C. uncinata	-	-	-	-	-	-	-	-	-	-	-	-	-
Clio pyramidata	-	-	12.5	-	-	-	-	-	-	-	-	-	-
Creseis sp.[15]	-	-	-	-	-	-	-	-	-	-	33.3	-	-
C. acicula	-	-	-	-	-	-	-	-	-	-	-	-	-
C. virgula	-	-	-	-	-	-	-	27.3	-	-	-	10.0	-
Cuvierina columnella	-	-	-	-	-	-	-	-	-	-	-	-	-
Diacria trispinosa	-	-	12.5	-	-	-	-	-	-	-	-	-	-
Limacina bulimoides	-	-	-	-	-	-	-	-	-	-	-	10.0	-
L. inflata	-	-	12.5	-	-	-	-	72.7	-	-	33.3	10.0	-
L. lesueuri	-	-	12.5	-	-	-	-	-	-	-	-	-	-
L. trochiformis	-	-	37.5	-	-	-	-	-	100.0	-	33.3	70.0	100.0
Styliola subula	-	-	12.5	-	-	-	-	-	-	-	-	-	-
Total Number per 1000 m³	0	0	8	0	0	0	0	11	6	0	3	10	1

[15] These are individuals of the genus Creseis whose lengths (<0.5 mm) were less than that of a complete embryonic shell and therefore could not be identified to species.

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Table 18
(continued)

CI-7206	Station Number												
	21	22	25	26	27	28	29	30	32	33	35	36	37
Cavolinia longirostris	10.0	-	13.6	-	-	-	-	66.7	-	-	-	-	-
C. tridentata	-	-	4.5	-	-	-	-	-	-	-	-	-	-
C. uncinata	10.0	-	-	-	-	-	-	-	-	-	-	-	-
Clio pyramidata	10.0	-	-	-	-	-	-	-	-	-	-	-	-
Creseis sp.[15]	10.0	-	-	-	-	-	12.5	-	-	0.6	-	-	-
C. acicula	-	-	4.5	-	-	18.1	-	-	-	2.2	-	-	-
C. virgula	-	-	-	-	-	-	12.5	-	33.3	2.2	-	-	-
Cuvierina columnella	10.0	50.0	4.5	-	-	9.1	-	-	-	1.1	-	-	-
Diacria trispinosa	-	50.0	-	22.2	-	-	-	-	-	-	-	-	-
Limacina bulimoides	-	-	-	22.2	-	-	-	-	-	0.6	-	-	-
L. inflata	20.0	-	31.8	-	-	18.1	37.5	-	66.7	16.3	-	-	-
L. lesueuri	-	-	-	-	-	-	-	-	-	-	-	-	-
L. trochiformis	30.0	-	36.3	55.6	-	45.5	37.5	33.3	-	72.5	-	50.0	-
Styliola subula	-	-	4.5	-	-	9.1	-	-	-	4.5	-	50.0	-
Total Number per 1000 m³	10	2	22	9	0	11	8	3	3	178	0	2	0

[15]These are individuals of the genus Creseis whose lengths (<0.5 mm) were less than that of a complete embryonic shell and therefore could not be identified to species.

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Table 19

Percentages of euthecosome species in samples collected
during CI-7309.

| CI-7309 | Station Number | | | | | |
	10	11	12	13	14	15
Creseis sp.[16]	35.5	57.1	11.8	14.6	-	-
C. acicula	6.5	14.3	11.8	10.4	-	-
C. virgula	35.5	-	23.5	36.5	75.0	50.0
Diacria quadridentata	-	-	-	-	25.0	-
Limacina trochiformis	22.6	14.3	52.9	38.5	-	50.0
Styliola subula	-	14.3	-	-	-	-
Total Number per 1000 m^3	31	14	17	96	8	9

[16]These are individuals of the genus Creseis whose
lengths (<0.5 mm) were less than that of a complete embry-
onic shell and therefore could not be identified to species.

Table 20

Percentages of euthecosome species in samples collected during CI-7317.

CI-7317	Station Number									
	1	2	3	4	5	6	9	10	11	12
Clio pyramidata	-	-	3.2	-	-	-	-	-	-	-
Creseis sp.[17]	-	-	-	50.0	10.8	-	-	-	-	33.3
C. acicula	-	62.5	-	50.0	8.1	16.7	-	-	-	33.3
C. virgula	-	-	3.2	-	8.1	-	25.0	-	-	-
Diacria trispinosa	-	12.5	3.2	-	-	-	-	-	-	-
D. quadridentata	-	12.5	-	-	-	-	-	-	-	-
Limacina inflata	-	12.5	80.6	-	-	-	-	-	-	-
L. lesueuri	-	-	-	-	-	-	-	-	50.0	-
L. trochiformis	-	-	-	-	64.9	83.3	75.0	-	50.0	33.3
Styliola subula	-	-	9.7	-	2.7	-	-	-	-	-
unknown euthecosome	-	-	-	-	5.4	-	-	-	-	-
Total Number per 1000 m³	0	8	31	2	74	6	2	0	2	3

[17] These are individuals of the genus Creseis whose lengths (<0.5 mm) were less than that of a complete embryonic shell and therefore could not be identified to species.

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Table 21

Percentages of euthecosome species in samples collected during CI-7401.

CI-7401	Station Number														
	1	3	5	6	7	8	9	12	13	14	16	18	19	20	21
Cavolinia sp.[18]	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
C. longirostris	-	-	-	1.7	-	26.9	-	-	-	-	-	15.8	5.9	-	-
Creseis sp.[19]	-	-	-	-	-	-	0.3	-	-	-	-	-	-	-	-
C. acicula	-	-	-	-	-	-	-	-	0.3	-	-	-	-	-	-
C. virgula	-	-	-	-	-	7.7	-	-	-	-	-	-	-	-	-
Cuvierina columnella	-	-	-	3.4	-	-	-	4.3	-	-	-	21.1	-	-	-
Diacria quadridentata	-	-	-	-	-	7.7	-	-	-	-	-	-	-	-	-
Limacina inflata	-	-	-	-	-	-	0.3	-	-	-	-	-	-	-	-
L. lesueuri	-	-	-	-	-	7.7	-	-	-	-	-	-	-	-	-
L. trochiformis	100.0	100.0	95.6	86.2	50.0	50.0	99.5	95.7	99.6	100.0	100.0	63.2	88.2	40.0	100.0
Styliola subula	-	-	4.3	8.6	-	-	-	-	-	-	-	-	5.9	60.0	-
unknown euthecosome[20]	-	-	-	-	50.0	-	-	-	-	-	-	-	-	-	-
Total Number per 1000 m³	39	2	23	58	6	26	742	69	592	44	11	38	34	5	1

[18]Following Haagensen (1976), all juveniles of Cavolinia smaller than 0.6-0.7 mm shell length were classified only as Cavolinia sp.

[19]These are individuals of the genus Creseis whose lengths (<0.5 mm) were less than that of a complete embryonic shell and therefore could not be identified to species.

[20]Same as unknown in CI-7317 (Table 20).

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recorded a mean day level (MDL) of 206 m and a mean night level (MNL) of 98 m at a station 10 miles off Miami and a MDL of 319 m and MNL of 167 m at a stion 40 miles east of Miami. Data in Haagensen (1976) and Myers (1968), however, indicate that this species is a non-migrator, confined to the upper 80 m. Wormelle's data for L. inflata at the 10-mile station shows almost identical values for MDL and MNL (236 m and 232 m). This suggests that L. inflata is a non-migrator, which contradicts Moore (1949), Chen (1962), Chen and Bé (1964), Myers (1968), and Haagensen (1976), all of whom found evidence for diurnal migration. A comparison of average depths and vertical ranges reported by Wormelle in the Florida Straits, Haagensen in the Caribbean, and Myers in the Hatteras region (Table 17) shows that many of Wormelle's results conflict with those of Haagensen and Myers. Her records and the unusual distributions reported in the present study are probably caused by the same physical phenomena.

The anomalous appearance of euthecosomes at 600 m, especially those species normally found only in the upper 100 m, provides evidence for the secondary circulation (sub- or supergeostrophy) postulated by Düing et al. (1977) and discussed earlier in the sections on deep flow reversals and chaetognaths. It is likely that some species are advected downward along the lower edge of the thermal front, roughly defined by the 10°C - 15°C isotherms, by a positive u-component during NWF which corresponds to the subgeostrophic regime. That the euthecosomes are associated with the front

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is apparent from Wormelle's (1962) work in the Straits. She found a positive correlation between the depth of the 15°C isotherm and the depth of the mean day level of the population.

To determine if a relationship existed between the deep distribution of the predominantly epipelagic euthecosomes and flow reversals, the numbers per 1000 m^3 of individual species were plotted on the same type of generalized graphs used to evaluate the species groupings of chaetognaths. On each graph (Figs. 43-54), the shaded areas represent pulses of SWF and the white background, NWF. Direction of the u-component in the water column is noted by sections labeled east and west and change in temperature, by plots of variation in the depth of the 10°C and 15°C isotherms. Black dots represent the depth of the plankton collections. Symbols (→←) on the lower axis in graphs for CI-7309 (Figs. 44 and 48) indicate profiles and samples taken out of the usual sampling sequence (0000, 0600, 1200 1800 hrs) at 2100 (P 3) and 1500 (P 7). The generalized graphs for CI-7401 (Figs. 46 and 50) show deep plankton collections through Station 15. Species data, however, are available for five additional stations (Table 21) during this survey. These data were not plotted due to lack of corresponding physical data caused by malfunction of the current meter. The occurrences of individual species and formae are tabulated in Appendix II, Tables 22-46, as adult, juvenile, and total numbers per 1000 m^3. Juveniles, which usually outnumbered adults, are

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reported separately. Since their response to changes in vertical structure did not differ from that of the adults, total numbers per 1000 m^3 are plotted on the generalized graphs.

As discussed in the METHODS, it was originally thought that the identification of infraspecific forms would aid in labeling a particular water mass. However, for the majority of species collected, only one forma, whose presence was not unexpected in the Florida Straits, was identified. Thus, with the exception of C. virgula f. conica and f. virgula, the relation of euthecosomes to changes in u, v, and t is discussed only at the species level. Data on the occurrence of the infrasubspecific forms are included in Appendix II as a contribution to the knowledge of world distribution at the forma level.

Analysis of the information contained in Figs. 43-54 concerning the occurrence of individual species during deep flow reversals is presented separately for non-migratory or feebly migratory species and for strongly migratory species.

Non-migratory or feebly migratory speces: Maximum numbers of the non- or feebly migratory euthecosomes Cavolinia longirostris, Creseis acicula, C. virgula, and Limacina trochiformis usually occur in the upper 100 m (Table 17). In the deep samples, C. longirostris was rarely collected (Figs. 43and 46), C. acicula, C. virgula, and Creseis sp.[21] were

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[21] These are individuals of the genus Creseis whose lengths (<0.5 mm) were less than that of a complete embryonic shell and therefore could not be identified to species.

126
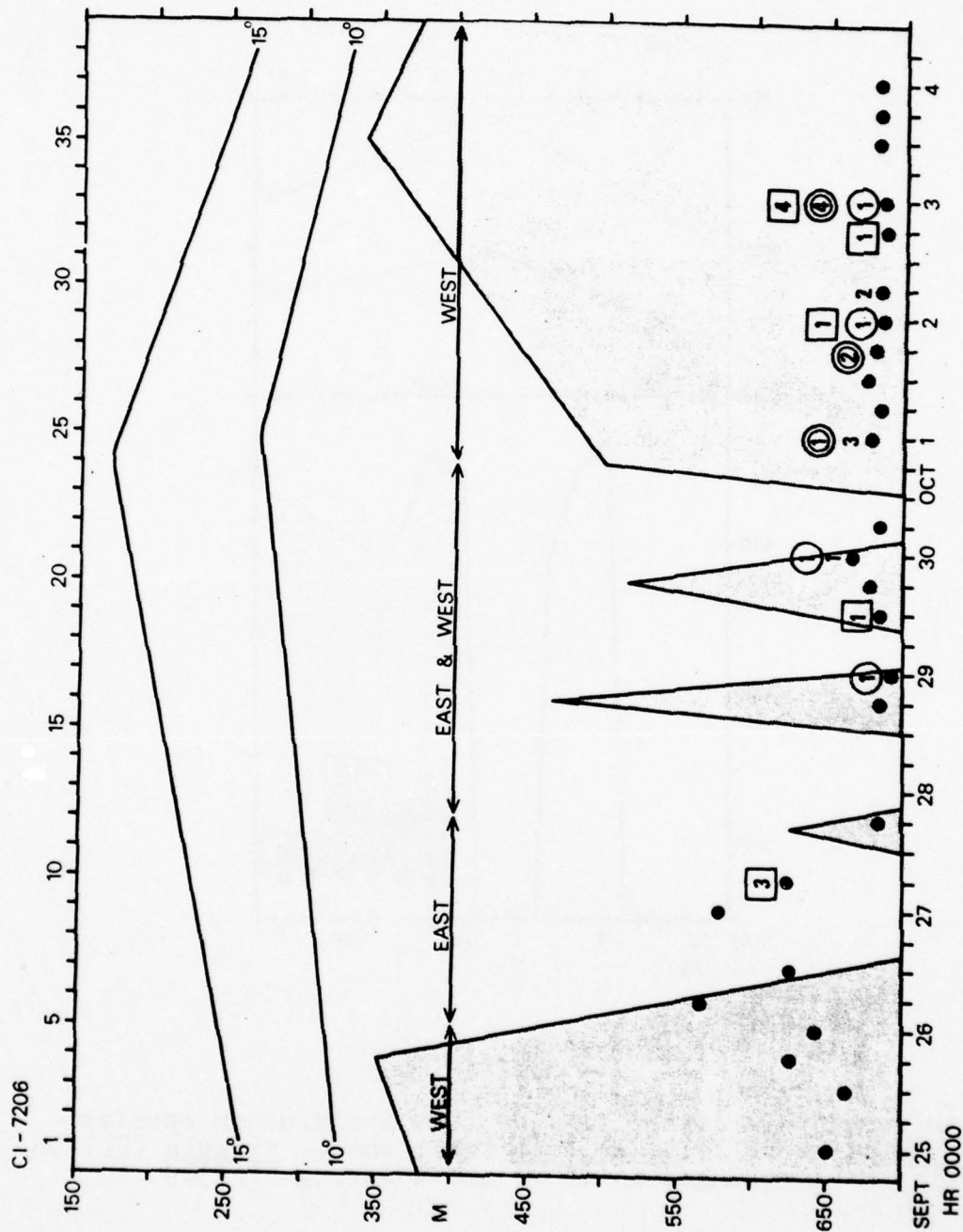
Figure 43

The occurrence of the non- or feebly migratory species
Cavolinia longirostris, Creseis sp. (O), C. acicula (◉),
and C. virgula (□) in relation to changes in u, v, and t
during CI-7206.

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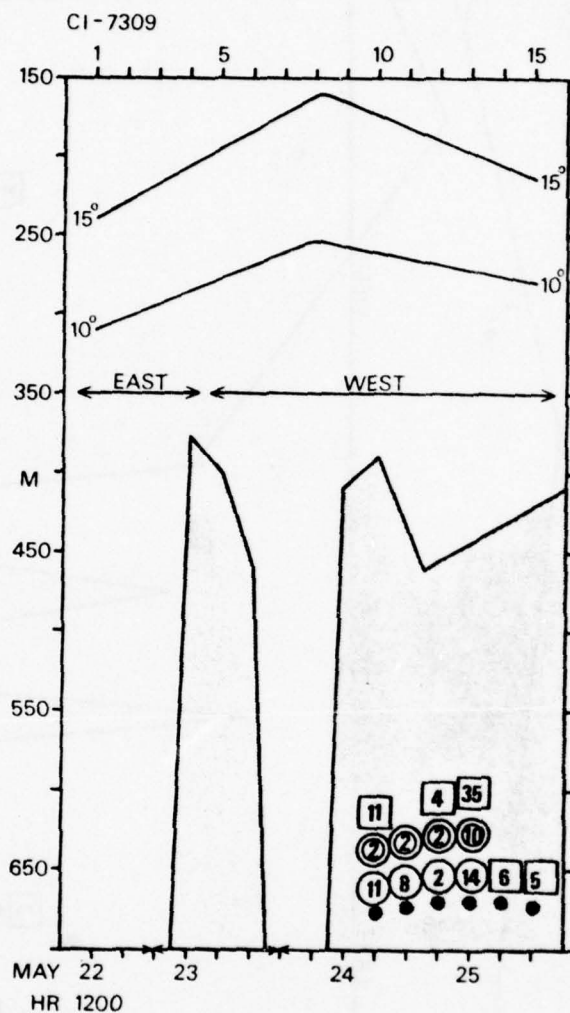
Figure 44

The occurrence of the non- or feebly migratory species
Creseis sp. (○), C. acicula (◎), and C. virgula (□) in
relation to changes in u, v, and t during CI-7309.

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CI-7317

15°   15°

10°   10°

WEST

M

04

6

1   6

1   1   6   ①①

5   1   8   ①   1

OCT 5 6   7   8

HR 1800
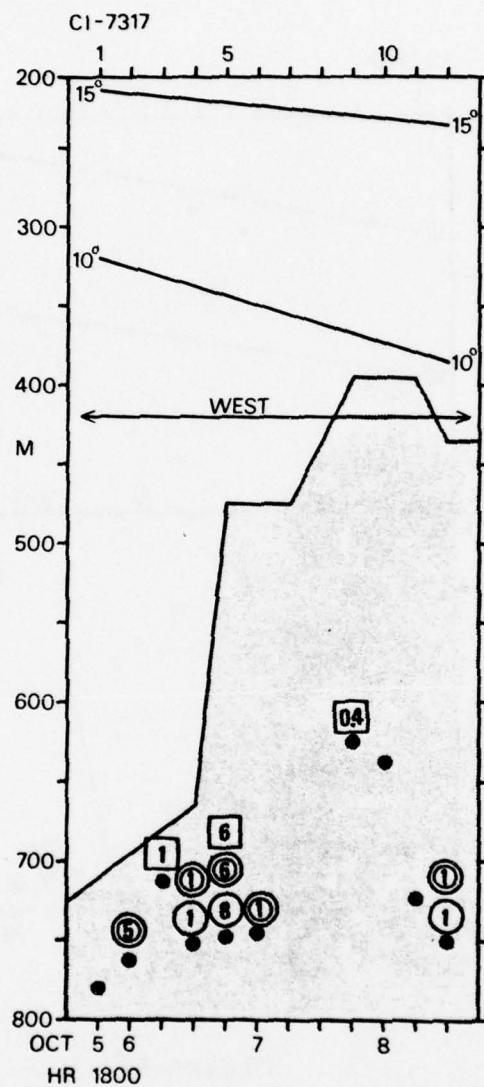
Figure 45

The occurrence of the non- or feebly migratory species
Creseis sp. (O), _C. acicula_ (◉), and _C. virgula_ (□) in
relation to changes in u, v, and t during CI-7317.

129
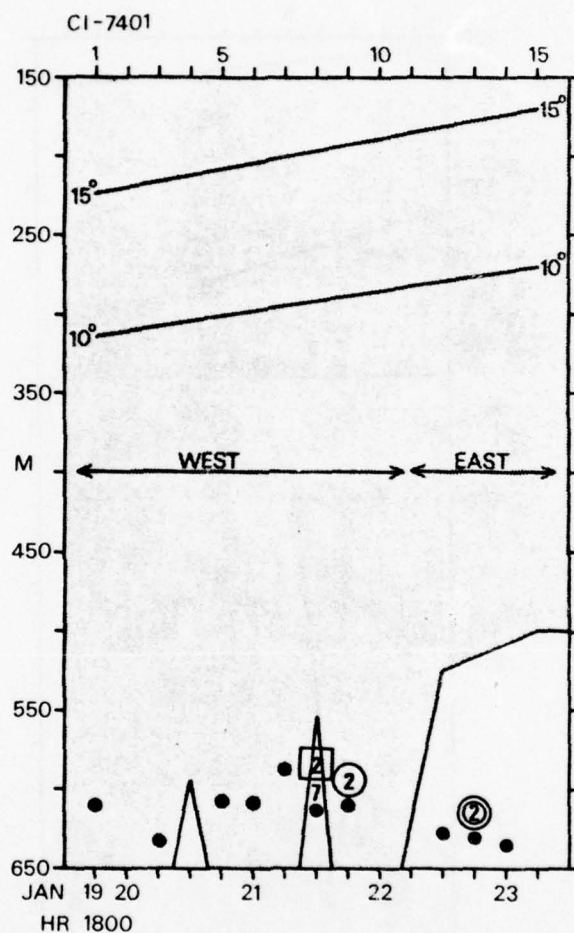
Figure 46

The occurrence of the non- or feebly migratory species
Cavolinia longirostris, Creseis sp. (O), C. acicula (◎),
and C. virgula (□) in relation to changes in u, v, and t
during CI-7401.

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relatively abundant (Figs. 43-46), and L. trochiformis, which includes juveniles of L. bulimoides or L. trochiformis (Appendix II, Tables 42 and 44), was the most commonly collected species (Figs. 47-50). The relative abundance of these species at 600 m compares favorably with Wormelle's data from the Florida Current (Table 22). Her percentages are average values of the total euthecosomes collected from 0 to 300 m (10-mile station) and 0 to 700 m (40-mile station) and agree best with the data from CI-7206, CI-7309, and CI-7317. The percentages for CI-7401 do not compare well with Wormelle's data owing to the large numbers of L. trochiformis collected (Fig. 50). Since Wormelle found maximum numbers of C. longirostris, C. acicula, C. virgula, and L. trochiformis in the upper 300 m (Table 22), the similarity between her relative abundances and those found at 600 m supports the concept of a contribution of shallow oceanic waters to the deep current.

The infrequently collected species Cavolinia longirostris, represented in the samples by the formae longirostris and strangulata, was collected in two sampling periods, CI-7206 and CI-7401 (Figs. 43 and 46). During CI-7206, it was found at the end of the transition period between NWF and SWF and during the following pulse of SWF. In CI-7401, it was collected once in a small pulse of NWF. The more frequently collected species Creseis sp., C. acicula, represented in certain samples by the forma acicula, and C. virgula, represented by the formae conica and virgula,

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Figure 47

The occurrence of the non-migratory species *Limacina trochiformis* and the strongly migratory species *L. inflata* (O) in relation to changes in u, v, and t during CI-7206.
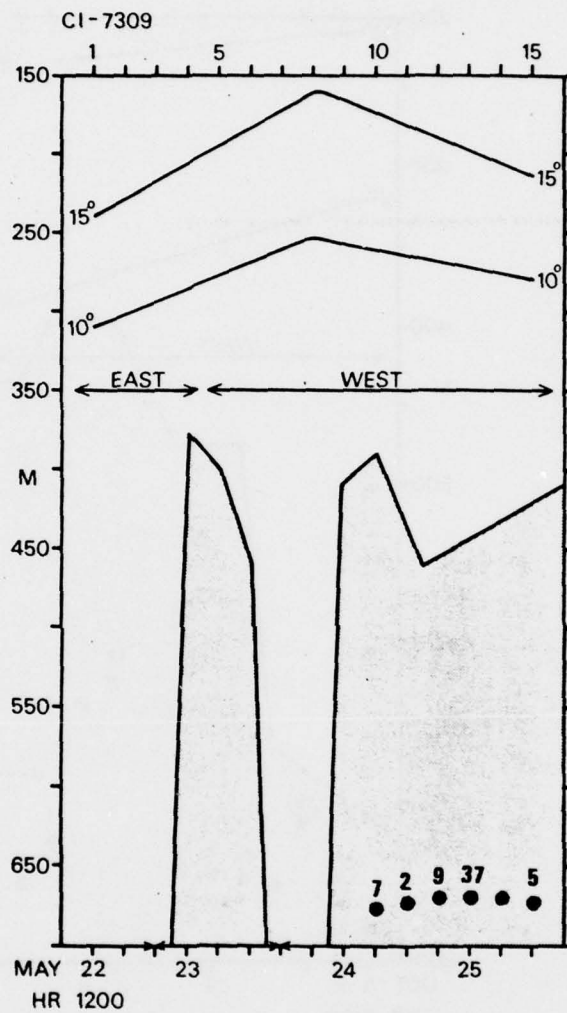
Figure 48

The occurrence of the non-migratory species <u>Limacina</u> <u>trochiformis</u> in relation to changes in u, v, and t during CI-7309.

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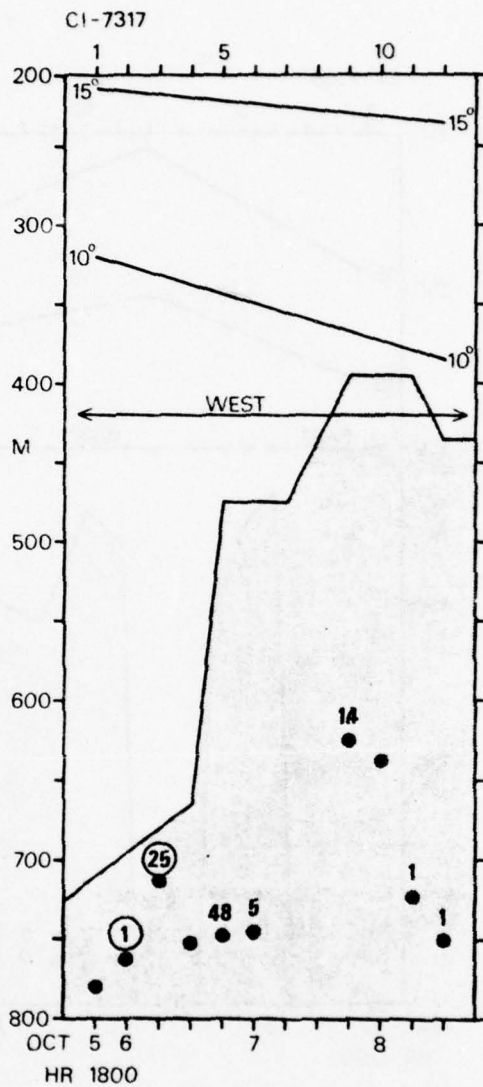
Figure 49

The occurrence of the non-migratory species <u>Limacina</u> <u>trochiformis</u> and the strongly migratory species <u>L</u>. <u>inflata</u> (O) in relation to changes in u, v, and t during CI-7317.
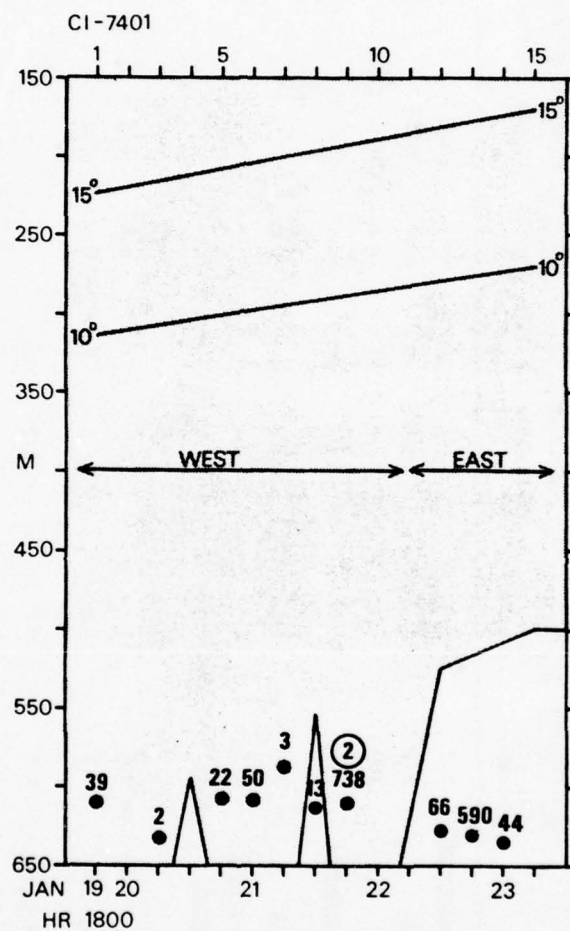
Figure 50

The occurrence of the non-migratory species <u>Limacina
trochiformis</u> and the strongly migratory species <u>L. inflata</u>
(◯) in relation to changes in u, v, and t during CI-7401.

Table 22

Relative percentages, number of times collected, and range in numbers per 1000 m³ of euthecosomes in the deep collections made during CI-7206, CI-7309, CI-7317, and CI-7401 compared with the relative abundance reported by Wormelle (1962) at 2 stations 10 and 40 miles east of Miami. Data for the deep collections are based on the total number of a given species per 1000 m³ for each sampling period.

| Species | Wormelle (1962) | | Deep Collections | | | | | |
	Per cent at 10-mile station	Per cent at 40-mile station	Per cent collected CI-7206	CI-7309	CI-7317	CI-7401	Number of times collected	Range in numbers per 1000 m³
Non-migratory or feebly migratory species:								
Cavolinia longirostris	3.3	5.0	2.1	-	-	0.1	6	1 - 7
Creseis acicula	8.9	11.2	2.4	9.1	10.9	0.1	13	1 - 10
C. virgula[22]	8.6	15.0	3.5	34.9	5.8	0.1	14	0.4 - 35
Limacina trochiformis	9.9	21.5	60.3	34.3	44.1	96.7	38	0.4 - 735
Strongly migratory species:								
Clio pyramidata	0.1	1.8	0.7	-	0.8	-	3	1
Cuvierina columnella	0.8	0.6	2.1	-	-	0.8	8	1 - 8
Limacina bulimoides	0.7	0.9	1.4	-	-	-	3	1 - 2
L. inflata	22.0	26.3	19.5	-	20.3	0.1	13	1 - 29
L. lecueuri	2.4	1.5	0.3	-	0.8	0.1	3	1 - 2
Styliola subula	3.0	5.3	4.2	1.1	3.9	0.7	12	1 - 8
Others:								
Cavolinia tridentata	1.4	0.7	0.3	-	-	-	1	1
C. uncinata	0.3	0.4	0.3	-	-	-	1	1
Diacria trispinosa	7.8	0.3	1.4	-	1.6	-	5	.1 - 2
D. quadridentata	8.5	1.3	-	1.1	0.8	0.1	3	1 - 2

[22]Wormelle did not distinguish infraspecific forms. For the purpose of comparison, percentages of C. virgula in the deep samples include both f. conica and f. virgula.

occurred during all four sampling periods. They were found in CI-7206 (Fig. 43) during NWF (C. virgula), in the transition period between NWF and SWF (C. sp. and C. virgula), and in the following pulse of SWF (C. sp., C. acicula, and C. virgula). All three occurred in CI-7309 and CI-7317 (Figs. 44 and 45) during SWF immediately after a pulse of NWF and in CI-7401 (Fig. 46). C. longirostris, C. sp., C. acicula, and C. virgula were all collected midway through, at the end of or immediately after, the rising and broadening of the 10°C and 15°C isotherms typical of the subgeostrophic regime.

The distribution of L. trochiformis, the most common euthecosome (Table 22), is similar to the other non- or feeble migrators, i.e., it is present at the end of and immediately following the subgeostrophic regime (Figs. 47-49). Its distribution during CI-7401 (Fig. 50), however, is especially unusual and clearly indicates a contribution of shallower oceanic waters to the deep current. L. trochiformis is a non-migratory species yet it was found from 550-650 m throughout CI-7401. At P 9, during SWF, 738 per 1000 m^3 were collected and, at P 13, 24 hrs later, a large number (590 per 1000 m^3), perhaps of the same population, was again caught in a pulse of NWF.

Strongly migratory species: With the exception of Limacina inflata, the strongly migrating species Clio pyramidata, represented by the forma lanceolata, Cuvierina columnella, present in certain samples as forma atlantica, Limacina bulimoides, L. lesueuri, and Styliola subula were

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relatively less abundant in the four sampling sets than the non- or feeble migrators (Table 22). In addition, the response of some of these species to changes in vertical structure was more random. This is to be expected since these species, although most common in the upper 200 m, do migrate to depths of 500 m or deeper and therefore might normally be present at the sampling depth in addition to being advected downward. The strongly migrating euthecosomes in the deep samples should respond to changes in vertical structure but, if their designation as strong migrators is correct, should occur less frequently, more randomly, and in smaller numbers than the non- or feeble migrators. These trends are apparent in the deep distribution patterns of the euthecosomes designated as strong migrators in this study. For example, during CI-7206 the more commonly collected strong migrators L. inflata, C. columnella, and S. subula (Figs. 47 and 51) generally respond to changes in vertical structure in a manner similar to that of the non-migratory euthecosomes and epipelagic chaetognaths, i.e., they are found most often at the end of and subsequent to a period of subgeostrophy. That the strong migrators occur more randomly is demonstrated by the infrequently collected species, C. pyramidata, L. bulimoides, and L. lesueuri. During CI-7206 (Fig. 52), they were found scattered at the beginning of, end of, and subsequent to a period of subgeostrophy. This is in contrast to the infrequently collected non-migrator Cavolinia longirostris (Fig. 43), the rare neritic

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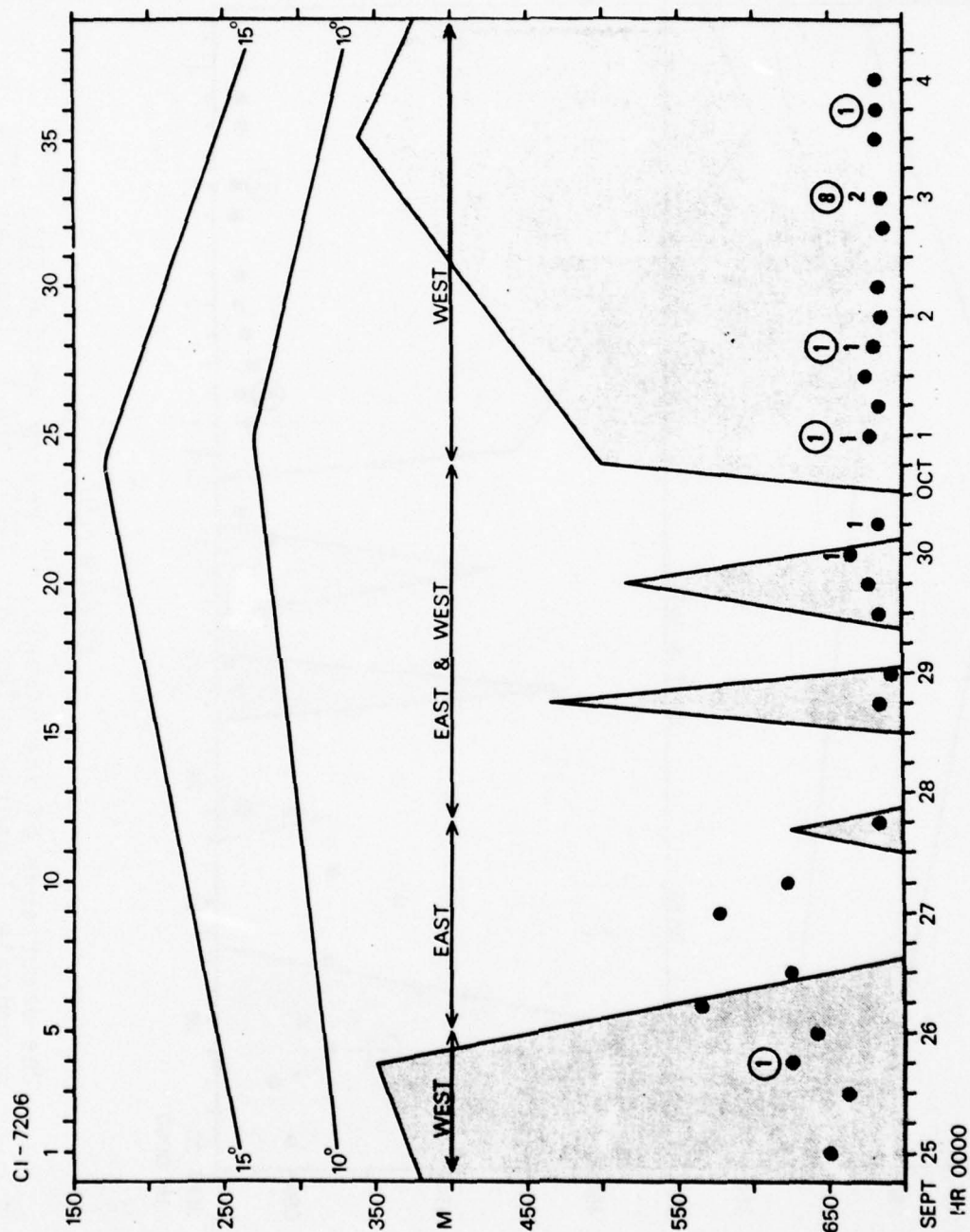
Figure 51

The occurrence of the strongly migratory species *Cuvierina*
columnella and *Styliola subula* (○) in relation to changes
in u, v, and t during CI-7205.

Figure 52

The occurrence of the strongly migratory species *Clio pyramidata*, *Limacina bulimoides* (O), and *L. lesueuri* (□) in relation to changes in u, v, and t during CI-7206.

chaetognaths <u>Sagitta</u> <u>helenae</u>, <u>S</u>. <u>hispida</u>, and <u>S</u>. <u>tenuis</u>
(Fig. 32), and the sporadically collected epipelagic oceanic
chaetognaths <u>Krohnitta</u> <u>pacifica</u> and <u>Pterosagitta</u> <u>draco</u>
(Fig. 33). These all occurred at 600 m during a pulse of
SWF following the subgeostrophic regime, and their presence
could be explained by downgliding along the edge of the
thermal front. <u>L</u>. <u>lesueuri</u> and <u>C</u>. <u>pyramidata</u> (Fig. 52),
which were collected less than 1.0% of the time, were absent
during the final pulse of SWF in CI-7206. These species are
not common in the Straits. Wormelle (1962) found them to
comprise 0.1% and 0.8% (<u>C</u>. <u>pyramidata</u>) and 2.4% and 1.5%
(<u>L</u>. <u>lesueuri</u>) of the total euthecosome population at the 10-
and 40-mile stations. Epipelagic chaetognaths collected in-
frequently at 600 m, and also relatively uncommon in the
Straits, typically appeared in the final pulse of SWF follow-
ing the rising and broadening of the isotherms. This is also
the case with the infrequently collected migrator <u>L</u>. <u>buli</u>-
<u>moides</u>. The distribution of <u>L</u>. <u>lesueuri</u> and <u>C</u>. <u>pyramidata</u>
in relation to changing vertical structure, however, suggests
that their presence may be due to their own downward migra-
tion. It is conceivable that, as a result of vertical
migration, these species might be absent in an area where
downward advection is occurring. If the main part of the
population of a species is migrating in and out of the
region where downwelling is occurring, it would be expected
that the numbers collected at 600 m would be proportionately
less than those of a non- or feeble migrator who theoreti-

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cally cannot avoid the downwelling area. This appears to
be the case when the numbers and frequency of occurrence at
600 m of L. trochiformis, a non-migrator, and L. inflata, a
strong migrator, are compared with known relative abundances
of the species in the Florida Straits. Wormelle (1962)
found L. inflata and L. trochiformis to be the most abundant
euthecosomes in the Florida Straits (Table 22). L. inflata
occurred most frequently, comprising 22.0% and 26.3% of the
euthecosomes at two stations 10 and 40 miles east of Miami.
L. trochiformis ranked second at both stations where it
occurred 9.9% and 21.5% of the time. In the deep samples,
L. inflata and L. trochiformis were also the most abundant
species but the relative proportions of the two species are
reversed. L. trochiformis was the most abundant, being
present 60.3% (CI-7206), 34.3% (CI-7309), 44.1% (CI-7317),
and 96.7% (CI-7401) of the time, with a range of 0.4-738 per
1000 m^3, while L. inflata was absent in CI-7309, but com-
prised 19.5%, 20.3%, and 0.1% of the population in CI-7206,
CI-7317, and CI-7401 and ranged from 1-29 per 1000 m^3 (Table
22). L. trochiformis was collected on 38 occasions and
regularly occurred in the deep samples during the four
sampling periods (Figs. 47-50), while L. inflata occurred
only 13 times, primarily during CI-7206 (Figs. 47, 49 and
50). That the relative abundances of L. inflata and L.
trochiformis are reversed and the occurrence of L. inflata
comparatively sporadic supports the classification of these
species as strongly migratory (L. inflata) and non-migratory

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(L. trochiformis). That the two most common euthecosomes in the upper 200 m in the Straits are also the most common at 600 m suggests a contribution from shallow oceanic waters.

All strong migrators, with the exception of S. subula, were absent from CI-7309 (Table 22) while the more common non- or feeble migrators C. acicula, C. virgula, and L. trochiformis were present throughout the sampling period. This suggests that most of the strongly migrating euthecosomes C. pyramidata, C. columnella, L. bulimoides, L. inflata, L. lesueuri, and S. subula may have migrated out of the region of downwelling during the period of subgeostrophy occurring from P 1-8 in CI-7309.

An attempt was made to relate the distribution patterns of the strongly migratory species to time of day but no correlation was apparent.

Others: Cavolinia tridentata f. bermudensis, C. uncinata uncinata f. uncinata, Diacria trispinosa, and D. quadridentata were relatively uncommon and, when present, never occurred in numbers greater than 2 per 1000 m^3 (Table 22). C. tridentata and C. uncinata, both collected only once, occurred in CI-7206 at the end of the transition period between NWF and SWF (Fig. 53). D. trispinosa also appeared in CI-7206 in the same portion of the time series (Fig. 53) and during CI-7317 (Fig. 54) at the beginning of a pulse of SWF. In each case the distribution of these species supports a contribution of shallower oceanic waters during the subgeostrophic regime. D. quadridentata was absent in CI-7206, but occurred once

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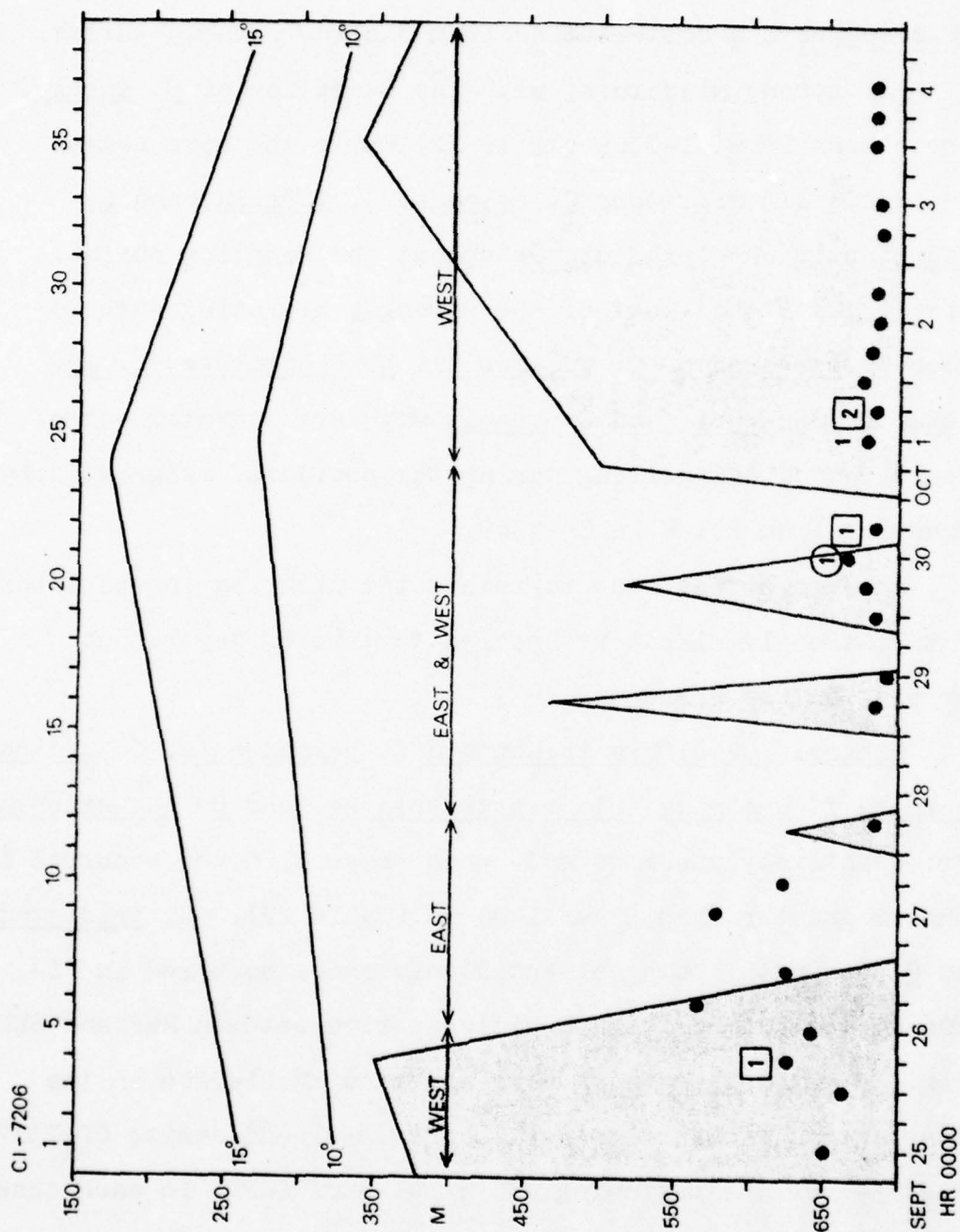
Figure 53

The occurrence of *Cavolinia tridentata*, *C. uncinata* (○), and *Diacria trispinosa* (□) in relation to changes in u, v, and t during CI-7206.
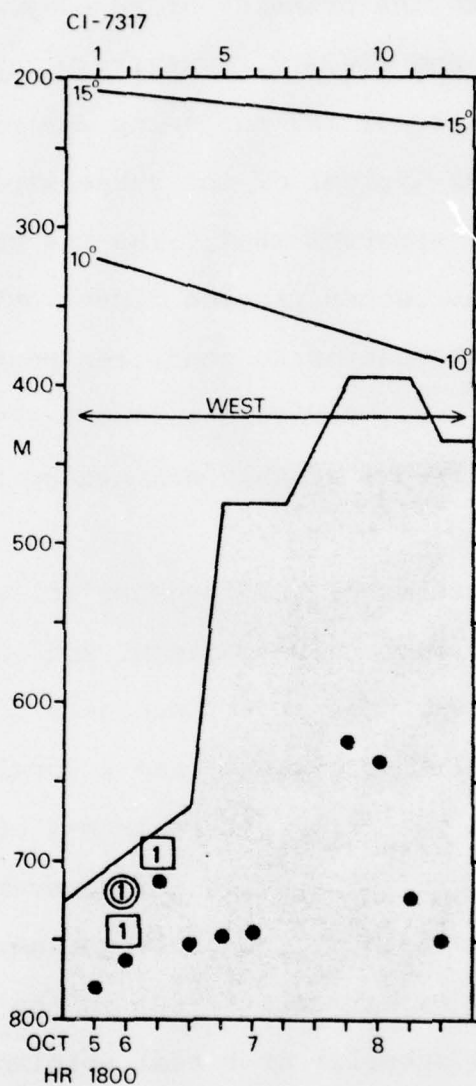
Figure 54

The occurrence of <u>Diacria</u> <u>trispinosa</u> (□) and <u>D</u>. <u>quadri-</u>
dentata (◎) in relation to changes in u, v, and t during
CI-7317.

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with $\underline{D}$. $\underline{trispinosa}$ in CI-7317 (Fig. 54) and was the only species in this group collected in CI-7309 and CI-7401. As discussed earlier, records from CI-7401 are difficult to interpret due to the presence of an eddy during the sampling. During CI-7309 and CI-7317, however, $\underline{D}$. $\underline{quadridentata}$ appeared in pulses of SWF following the rising and broadening of the isotherms typical of the subgeostrophic condition.

It is thus apparent that, like the chaetognaths, the epipelagic euthecosomes provide direct evidence for the hypothetical subgeostrophic condition postulated by Düing et al. (1977), i.e., downward movement along the lower edge of the thermal front, roughly defined by the 10°C and 15°C isotherms.

Certain species of chaetognaths collected during SWF in-dicated a contribution from coastal and oceanic areas to the north. Historical data on euthecosomes collected off Miami (Wormelle, 1962) also suggest that a portion of the water associated with deep flow reversals may originate in oceanic areas to the north. The evidence, however, is not as conclu-sive as that provided by the Chaetognatha. $\underline{Limacina}$ $\underline{retro}$-$\underline{versa}$, reported by Wormelle (1962) in the Florida Straits off Miami, is a subpolar or boreal epiplanktonic form most commonly found in the upper 150 m (Bé and Gilmer, 1977). It is a bipolar species in the Atlantic Ocean and, in the North Atlantic, extends only as far south as Cape Hatteras (Myers, 1968). It was not reported by Hughes (1968), Austin (1971), or Williams (1972) in the Gulf of Mexico or by Haagensen

(1976) in the Caribbean. Myers (1968), when discussing
Wormelle's data on L. retroversa, stated: "If these identi-
fications are correct, this would be supporting evidence for
southward movement of pieces of Virginian water all the way
to the Florida Straits." L. retroversa was not recorded
from the deep samples in this study. This, however, may have
been due to the rareness of the species (Wormelle found only
6 specimens) rather than its absence.

Euphausiacea

Like the chaetognaths and the euthecosomes, euphausiids
are widely distributed in the world oceans. Since they are
comparatively powerful swimmers, best caught by nets and
midwater trawls towed at relatively high speeds (James, 1970;
Roger, 1974; Michel et al., 1976; Wiebe et al., 1976), they
probably avoided the stationary net used in this study, as
indicated by the small numbers collected compared with the
numbers of chaetognaths and euthecosomes (Table 23). In
addition, many species perform diurnal vertical migrations
of several hundred meters, and "epipelagic" forms are there-
fore known to occur in numbers over wide depth ranges, in
contrast to chaetognaths and euthecosomes. The presence of
most species at 600 m is not necessarily anomalous although,
as will be shown, the deep distribution of certain non-
migrating species does provide information on changing physi-
cal conditions in the Current.

Fifteen species, representing six genera, were iden-

Table 23

Relative percentages of Chaetognatha, Euthecosomata,
and Euphausiacea collected in the deep samples during
CI-7206, CI-7309, CI-7317, and CI-7401.

Cruise	Station	Chaetognatha	Euthecosomata	Euphausiacea
CI-7206	1	100.0	-	-
	3	100.0	-	-
	4	72.0	18.6	9.3
	5	100.0	-	-
	6	-	-	-
	7	100.0	-	-
	9	100.0	-	-
	10	36.4	50.0	13.6
	12	50.0	50.0	-
	16	95.2	-	4.8
	17	25.0	75.0	-
	19	28.6	71.4	-
	20	97.0	3.0	-
	21	25.0	62.5	12.5
	22	38.9	11.1	50.0
	25	9.7	71.0	19.4
	26	57.1	42.9	-
	27	-	-	-
	23	73.9	23.9	2.2
	29	31.6	42.1	26.3
	30	66.7	14.3	19.0
	32	50.0	37.5	12.5
	33	25.4	62.9	11.7
	35	100.0	-	-
	36	90.5	9.5	-
	37	-	-	-
CI-7309	10	20.5	79.5	-
	11	33.3	66.7	-
	12	24.0	68.0	8.0
	13	21.0	77.4	1.6
	14	77.8	22.2	-
	15	75.0	20.5	4.5
CI-7317	1	66.7	-	33.3
	2	20.0	80.0	-
	3	35.5	25.0	39.5
	4	60.0	40.0	-
	5	28.2	71.8	-
	6	45.5	54.5	-
	9	85.0	10.0	5.0
	10	100.0	-	-
	11	75.0	25.0	-

Table 23
(continued)

Cruise	Station	Chaetognatha	Euthecosomata	Euphausiacea
	12	71.4	21.4	7.1
CI-7401	1	23.5	76.5	-
	3	57.1	28.6	14.3
	5	49.0	46.9	4.1
	6	23.5	71.6	4.9
	7	20.0	60.0	20.0
	8	23.5	76.5	-
	9	0.9	98.5	0.5
	12	21.6	78.4	-
	13	0.3	99.7	-
	14	-	95.7	4.3
	16	57.1	31.4	11.4
	18	26.5	55.9	17.6
	19	7.7	87.2	5.1
	20	22.2	27.8	50.0
	21	-	100.0	-

tified from the samples. These are:

Bentheuphausia amblyops G.O. Sars, 1885

Euphausia americana Hansen, 1911

E. hemigibba Hansen, 1910

E. mutica Hansen, 1905

E. pseudogibba Ortmann, 1893

E. tenera Hansen, 1905

Nematobrachion boopis (Calman, 1905)

N. flexipes (Ortmann, 1893)

Nematoscelis atlantica Hansen, 1910

N. microps G.O. Sars, 1883

N. tenella G.O. Sars, 1883

Stylocheiron abbreviatum G.O. Sars, 1883

S. carinatum G.O. Sars, 1883

S. elongatum G.O. Sars, 1883

Thysanopoda obtusifrons G.O. Sars, 1883

All have been reported from the Florida Straits or the
Caribbean, Gulf of Mexico, or North Atlantic off the conti-
nental United States (Table 24). Three, Bentheuphausia
amblyops, Euphausia pseudogibba, and Thysanopoda obtusifrons,
are new records for the Straits off Miami.

The species identified in the deep samples can be classi-
fied as epipelagic (0-700 m), mesopelagic (140-1000 m), or
bathypelagic (>500 m) (Brinton, 1962) on the basis of
numerous studies on the vertical distribution and migration
patterns of euphausiids (Table 25). The ranges for the epi-,
meso-, and bathypelagic zones differ from those used for the

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Table 24

Previous records from the Caribbean, Gulf of Mexico, Florida Straits, and the North Atlantic off the continental United States of euphausiid species reported in this study. Additional records of Atlantic distribution have been summarized by Mauchline and Fisher (1969).

Species	Caribbean[23]	Gulf of Mexico[24]	Florida Straits[25]	North Atlantic off continental United States[26]
Bentheuphausia amblyops[27]	-	+	-	+
Euphausia americana	+	+	+	+
E. hemigibba	+	+	+	+
E. mutica	+	+	+	+
E. pseudogibba	+	+	-	+
E. tenera	+	+	+	+
Nematobrachion boopis	+	+	+	+
N. flexipes	+	+	+	+
Nematoscelis atlantica	+	+	+	+
N. microps	+	+	+	+
N. tenella	+	+	+	+

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Table 24
(continued)

Species	Caribbean[23]	Gulf of Mexico[24]	Florida Straits[25]	North Atlantic off continental United States[26]
Stylocheiron abbreviatum	+	+	+	+
S. carinatum	+	+	+	+
S. elongatum	+	+	+	+
Thysanopoda obtusifrons	+	+	-	+

[23]Hansen (1915); Legaré (1961); Lewis and Fish (1969); Mauchline and Fisher (1969); Owre and Foyo (1972); Michel et al. (1976).

[24]Hansen (1915); Moore (1950, 1952); Banner (1954); Springer and Bullis (1956); Mauchline and Fisher (1969); James (1970, 1971); Schroeder (1971); Michel et al. (1976).

[25]Tattersall (1926); Moore (1950, 1952); Lewis (1954); Mauchline and Fisher (1969); Michel et al. (1976).

[26]Ortmann (1893); Hansen (1915); Bigelow (1917, 1926); Tattersall (1926, 1936); Leavitt (1935, 1938); Moore (1949, 1950, 1952); Lebour (1950); Grice and Hart (1962); Soulier (1965); Mauchline and Fisher (1969); Gopalakrishnan (1973, 1974); Wiebe (1976); Wiebe et al. (1976).

[27]The author has identified B. ambylops from samples collected with a 2 m macroplankton net (Owre [Michel] and Low, 1976) towed at high speeds in the Yucatan Channel. Its absence in previous Caribbean collections is probably due to inadequate sampling.

Table 25

Bathymetric distribution and migration patterns of euphausiid species collected in this study based on reports by Leavitt (1935, 1938), Moore (1949), Lewis (1954), Brinton (1962, 1967), Mauchline and Fisher (1969), Baker (1970), James (1970), Schroeder (1971), Roe (1974), Roger (1974), Youngbluth (1975, 1976), and Michel et al. (1976).

	Non- or Short Distance Migrants	Migrants
Epipelagic (0-700 m)	Stylocheiron abbreviatum S. carinatum	Euphausia americana E. hemigibba E. mutica E. pseudogibba E. tenera Nematobrachion flexipes Nematoscelis atlantica N. microps Thysanopoda obtusifrons
Mesopelagic (140-1000 m)	Nematobrachion boopis Nematoscelis tenella Stylocheiron elongatum	
Bathypelagic (>500 m)		Bentheuphausia amblyops

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chaetognaths and euthecosomes. These terms are broadly
useful in describing the vertical ranges of species and have
been defined differently by various authors depending on the
geographic area and the group of animals studied. Brinton's
(1962) classification has been adopted here since it seems
to fit best the vertical distribution patterns reported by
many investigators including those cited in Table 25.

The daily vertical migration patterns of euphausiids,
identified in this study, in the Caribbean (Michel et al.,
1976), Gulf of Mexico (Schroeder, 1971), Florida Straits
(Lewis, 1954), and Atlantic Ocean in the vicinity of the
Canary Islands (Baker, 1970) have been summarized in Table
26. As seen in this table, there is considerable overlap
in the vertical ranges of the epipelagic, mesopelagic, and
bathypelagic forms. The presence of most of these species
at 600 m would not be unusual, although that of Stylocheiron
abbreviatum and S. carinatum is atypical (Moore, 1949;
Schroeder, 1971; Roger, 1974; Youngbluth, 1975; Michel et al.,
1976; P. Wiebe, personal communication), and suggests a
contribution from shallower waters.

Lewis' (1954) description of the vertical distribution
of twenty species of euphausiids in the Florida Straits off
Miami also indicates that some specimens were derived from
shallower waters. Table 26 shows that the vertical distri-
butions reported by Lewis generally compare favorably with
those recorded in adjacent regions. However, the vertical
ranges or levels of maximum abundance of several species,

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Table 26

Diurnal migration patterns of adult euphausiid species discussed in this study as reported in the Caribbean (Michel et al., 1976), Gulf of Mexico (Schroeder, 1971), Florida Straits (Lewis, 1954), and the Canary Islands (Baker, 1970). Numbers in parentheses are day and night levels of maximum abundance.

Species	Michel et al. (1976) Caribbean Day Range	Night	Schroeder (1971) Gulf of Mexico Day	Night	Lewis (1954) Florida Straits Day	Night	Baker (1970) Canary Islands Day	Night
Epipelagic:								
Euphausia americana	0-2500 m (250-500)	(<55)	330-459 m	0-249 m (30-100)	275-730 m (450-550)	0-730 (sfc)	-	28
E. hemigibba	53-590 (350-510)	(53-90)	410-459	80-349	0-730 (450-640)	0-730 (450)	360-940 (400-610)	0-960
E. mutica	0-500 (250-500)	(<100)	310-479 (390-409)	0-209 (80-109)	180-730 (450-550)	0-730 (sfc)	absent	
E. pseudogibba	55-550 (250-550)		400-449	80-299 (80-169)	absent		absent	
E. tenera	0-1000 (>224)	(<100)	250-509	0-509 (<200) 28	0-730 (275-365)	0-730 (sfc)	absent	28
Nematobrachion flexipes	45-2454		-	- 28	absent		-	
Nematoscelis[29] atlantica	132-781 (<250)		40-459	0-469 (130-289)	-	28	50-950 (470-610)	50-710 (170-460)
N. microps[29]	-		-	-	-	-	-	28
Stylocheiron abbreviatum	220-297		0-479 (390-409)	0-400 (150)	320-730 (550-640)	0-640 (180-275) 28	-	-
S. carinatum	0-285		0-489 (90-149)	0-469 (100) 28	0-730 (90-180)	0-550 (180-275)	-	-
Thysanopoda obtusifrons	55-550		-	-	absent		500-760 (590-620)	100-760
Mesopelagic:								
Nematobrachion boopis	420-1000		-	28	-	28	50->500 (590-620)	400-760

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Table 26
(continued)

Species	Michel et al. (1976) Caribbean Day Range Night		Schroeder (1971) Gulf of Mexico Day Night		Lewis (1954) Florida Straits Day Night		Baker (1970) Canary Islands Day Night	
Nematoscelis tenella	218-590	28	>400	>400	365-730 (640-730)	140-730 (180-275)	200-900 (400-600)	50-580 (220-360)
Stylocheiron elongatum	—		280-509 (>430)	230-489 (<380)	275-730 (275-365)	180-730	150-590 (220-360)	150-700 (240-380)
Bathypelagic:								
Bentheuphausia amblyops	absent		absent		absent		absent	
Sampling Range (m)	0-7500		0-520		0-730		0-1000	
Gear Used	Opening-Closing Modified Discovery Net		Longhurst-Hardy Plankton Recorder		Closing Modified Discovery Net		N-113, IKMT, and Neuston Nets	

[28] Migration patterns could not be evaluated due to small numbers collected.

[29] Due to difficulty in separating the adolescents and adult females of N. atlantica and N. microps, Baker (1970), Schroeder (1971), and Michel et al. (1976) considered the two species as one, N. microps/atlantica. This problem has been solved by Gopala-krishnan (1975).

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e.g., _E_. _hemigibba_, _E_. _mutica_, and _S_. _carinatum_, are lower
in the Straits than in the Caribbean and the Gulf of Mexico.
Possibly the secondary circulation postulated by Düing _et_ _al_.
(1977) and supported by the anomalous distribution of epi-
pelagic chaetognaths and euthecosomes also accounts for the
deeper distribution of these species. For example, the
epipelagic non-migrator _S_. _carinatum_, usually collected only
in the upper 300 m (Roger, 1974; Michel _et_ _al_., 1976; P.
Wiebe, personal communication), was recorded by Lewis at
730 m in the Straits off Miami.

The occurrence of most species of euphausiids collected
in the deep samples (Tables 27-30), however, cannot be linked
to sub- or supergeostrophy with certainty. Whereas the
chaetognaths and euthecosomes are passively advected along
the edge of the front, the actively swimming euphausiids can
either follow the edge of the front or migrate through it.
That most euphausiids are not associated with the front in
the same manner as the chaetognaths and euthecosomes is
apparent from Lewis' (1954) study in the Straits. He found
no correlation between the depth of the 15°C isotherm and the
depth above which half of the individuals occurred, whereas
Wormelle (1962), working in the same area, found a positive
correlation between the depth of the 15°C isotherm and the
depth of the mean day level of the euthecosome population.
Thus, the euphausiids provide little direct evidence for the
secondary circulation postulated by Düing _et_ _al_. (1977).
This conclusion is supported by analysis of the generalized

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Table 27

Percentages of euphausiid species in samples collected during CI-7206.

CI-7206	1	3	4	5	6	7	9	10	12	16	17	19	20
Euphausia americana	–	–	–	–	–	–	–	–	–	–	–	–	–
E. hemigibba	–	–	25.0	–	–	–	–	–	–	–	–	–	–
E. mutica	–	–	25.0	–	–	–	–	–	–	100.0	–	–	–
E. pseudogibba	–	–	–	–	–	–	–	–	–	–	–	–	–
E. tenera	–	–	–	–	–	–	–	–	–	–	–	–	–
Nematoscelis atlantica	–	–	–	–	–	–	–	–	–	–	–	–	–
N. microps	–	–	–	–	–	–	–	–	–	–	–	–	–
N. tenella	–	–	–	–	–	–	–	–	–	–	–	–	–
Stylocheiron abbreviatum	–	–	–	–	–	–	–	–	–	–	–	–	–
S. carinatum	–	–	–	–	–	–	–	100.0	–	–	–	–	–
S. elongatum	–	–	–	–	–	–	–	–	–	–	–	–	–
immatures	–	–	50.0	–	–	–	100.0	–	–	–	–	–	–
Total Number per 1000 m³	0	0	4	0	0	0	0	3	0	1	0	0	0

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Table 27
(continued)

CI-7206	Station Number												
	21	22	25	26	27	28	29	30	32	33	35	36	37
Euphausia americana	50.0	22.2	-	-	-	-	40.0	50.0	-	6.1	-	-	-
E. hemigibba	-	11.1	-	-	-	-	-	25.0	-	-	-	-	-
E. mutica	-	-	-	-	-	-	20.0	-	-	3.0	-	-	-
E. pseudogibba	-	-	16.7	-	-	-	20.0	-	-	-	-	-	-
E. tenera	-	11.1	33.3	-	-	-	-	-	-	63.6	-	-	-
Nematoscelis atlantica	-	22.2	16.7	-	-	-	-	-	-	-	-	-	-
N. microps	-	22.2	-	-	-	-	-	-	-	-	-	-	-
N. tenella	-	-	-	-	-	-	-	25.0	-	-	-	-	-
Stylocheiron abbreviatum	50.0	-	16.7	-	-	-	-	-	-	-	-	-	-
S. carinatum	-	-	16.7	-	-	-	-	-	-	-	-	-	-
S. elongatum	-	11.1	-	-	-	-	-	-	-	-	-	-	-
immatures	-	-	-	-	-	100.0	20.0	-	100.0	27.3	-	-	-
Total Number per 1000 m³	2	9	6	0	0	1	5	4	1	33	0	0	0

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Table 28

Percentages of euphausiid species in samples collected
during CI-7309.

CI-7309	Station Number					
	10	11	12	13	14	15
Bentheuphausia amblyops	-	-	-	-	-	100.0
Euphausia americana	-	-	100.0	-	-	-
immatures	-	-	-	100.0	-	-
Total Number per 1000 m³	0	0	2	2	0	2

Table 29

Percentages of euphausiid species in samples collected during CI-7317.

CI-7317				Station Number						
	1	2	3	4	5	6	9	10	11	12
Euphausia sp.[30]	–	–	8.2	–	–	–	–	–	–	–
E. americana	–	–	2.0	–	–	–	–	–	–	–
E. hemigibba	–	–	2.0	–	–	–	50.0	–	–	–
E. pseudogibba	–	–	6.1	–	–	–	–	–	–	–
E. tenera	–	–	26.5	–	–	–	–	–	–	–
Nematobrachion flexipes	100.0	–	–	–	–	–	–	–	–	–
Nematoscelis atlantica	–	–	2.0	–	–	–	50.0	–	–	–
Stylocheiron abbreviatum	–	–	–	–	–	–	–	–	–	100.0
Thysanopoda obtusifrons	–	–	2.0	–	–	–	–	–	–	–
immatures	–	–	51.0	–	–	–	–	–	–	–
Total Number per 1000 m³	1	0	49	0	0	0	1	0	0	1

[30]Unidentifiable specimens of *Euphausia*.

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Table 30

Percentages of euphausiid species in samples collected during CI-7401.

CI-7401							Station Number								
	1	3	5	6	7	8	9	12	13	14	16	18	19	20	21
Euphausia americana	-	-	50.0	25.0	-	-	50.0	-	-	-	-	-	-	-	-
E. hemigibba	-	-	-	-	-	-	-	-	-	-	-	50.0	100.0	22.2	-
E. tenera	-	-	-	25.0	-	-	-	-	-	100.0	-	-	-	22.2	-
Nematobrachion boopis	-	-	-	25.0	-	-	-	-	-	-	-	-	-	-	-
Nematoscelis microps	-	100.0	-	25.0	100.0	-	-	-	-	-	-	33.3	-	-	-
N. tenella	-	-	-	-	-	-	-	-	-	-	-	16.7	-	-	-
Stylocheiron abbreviatum	-	-	-	-	-	-	-	-	-	-	50.0	-	-	-	-
S. carinatum	-	-	50.0	-	-	-	50.0	-	-	-	-	-	-	-	-
immatures	-	-	-	-	-	-	-	-	-	-	50.0	-	-	55.6	-
Total Number per 1000 m³	0	1	2	4	2	0	4	0	0	2	4	12	2	9	0

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graphs (Figs. 55-57) on which the numbers per 1000 m^3 of indi-
vidual species (Appendix II, Tables 47-63) are plotted. On
each graph, the shaded areas represent pulses of SWF and the
white background, NWF. Direction of the u-component in the
water column is noted by sections labeled east and west and
change in temperature by plots of variation in the depth of
the 10°C and 15°C isotherms. Black dots represent the level
of the deep plankton collections.

Epipelagic migrant species: The epipelagic migrants
Euphausia americana, E. hemigibba, E. mutica, E. pseudogibba,
E. tenera, Nematobrachion flexipes, Nematoscelis atlantica,
N. microps, and Thysanopoda obtusifrons were captured more
frequently and in larger numbers than the epipelagic non-
migrant, mesopelagic, and bathypelagic species (Table 31).
E. americana was the only species collected during all
sampling periods and E. tenera was the most common. In con-
trast to the chaetognaths and euthecosomes, the relative
abundances of individual euphausiid species are difficult to
evaluate in terms of historical data due to the small numbers
collected. For example, Lewis (1954), Schroeder (1971), and
Michel et al. (1976) ranked E. tenera first or second in the
Florida Straits, Gulf of Mexico, and Caribbean. This corre-
sponds to its rank in the present study. However, they also
found S. carinatum to rank second (Lewis, 1954), first
(Schroeder, 1971), and fourth (Michel et al., 1976) in the
same respective areas. In the present study, S. carinatum
was collected only three times. Similar discrepancies are

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Table 31

Relative percentages, number of times collected, and range in numbers per 1000 m³ of euphausiids in the deep samples collected during CI-7206, CI-7309, CI-7317, and CI-7401. [Percentages are based on the total number of a given species per 1000 m³ for each sampling period.]

| Species | Per cent collected | | | | Number of times collected | Range in numbers per 1000 m |
	CI-7206	CI-7309	CI-7317	CI-7401		
Epipelagic migrant species:						
Euphausia sp. [3]	-	-	7.7	-	1	4
E. americana	14.5	33.3	1.9	9.5	11	1 - 2
E. hemigibba	5.8	-	2.7	23.8	9	0.4 - 6
E. mutica	2.9	-	-	-	2	1
E. pseudogibba	2.9	-	5.8	-	3	1 - 3
E. tenera	34.8	-	25.0	11.9	7	1 - 21
Nematobrachion flexipes	-	-	1.9	-	1	1
Nematoscelis atlantica	4.3	-	2.7	-	4	0.4 - 2
N. microps	2.9	-	-	19.0	5	1 - 4
Thysanopoda obtusifrons	-	-	1.9	-	1	1
Epipelagic non-migrant species:						
Stylocheiron abbreviatum	2.9	-	1.9	4.8	4	1 - 2
S. carinatum	1.4	-	-	7.1	3	1 - 2
Meso-, bathy-pelagic species:						
Bentheuphausia amblyops	-	33.3	-	-	1	2
Nematobrachion boopis	-	-	-	2.4	1	1
Nematoscelis tenella	1.4	-	-	4.8	2	1 - 2
Stylocheiron elongatum	1.4	-	-	-	1	1
Immatures:	24.6	33.3	48.1	16.7	10	1 - ?

[3] Unidentifiable specimens of Euphausia.

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apparent when the relative abundances of other euphausiids identified from the deep samples are compared with the data of Lewis, Schroeder and Michel et al.

E. americana, E. hemigibba, and E. tenera, as well as the relatively less common epipelagic migrants E. mutica, E. pseudogibba, N. flexipes, N. atlantica, N. microps, and T. obtusifrons, were collected primarily during pulses of SWF, following the rising and broadening of the isotherms characteristic of the subgeostrophic regime. This is evident in the generalized graphs of their distributions (Figs. 55 and 56) during CI-7206. The distributions shown in these figures are similar to those of the epipelagic chaetognaths and euthecosomes (Figs. 32-40 and 43-50) and suggest a relation between deep flow reversals and euphausiid distribution. However, due to vertical migration and avoidance, the frequency of occurrence and numbers collected are too small to reveal any definite trends. An attempt was also made to relate the distribution patterns to time of day but no correlation was found.

Epipelagic non- or short distance migrants: These are the only euphausiids whose deep distribution patterns suggest a downwelling of shallower oceanic waters. Stylocheiron abbreviatum and S. carinatum were collected during CI-7206 and CI-7401 and S. abbreviatum during CI-7317, in numbers ranging from 1-2 per 1000 m^3 (Table 31). Since S. carinatum is usually found only in the upper 300 m, its occurrence at 600 m is a distributional anomaly. S. abbreviatum, though

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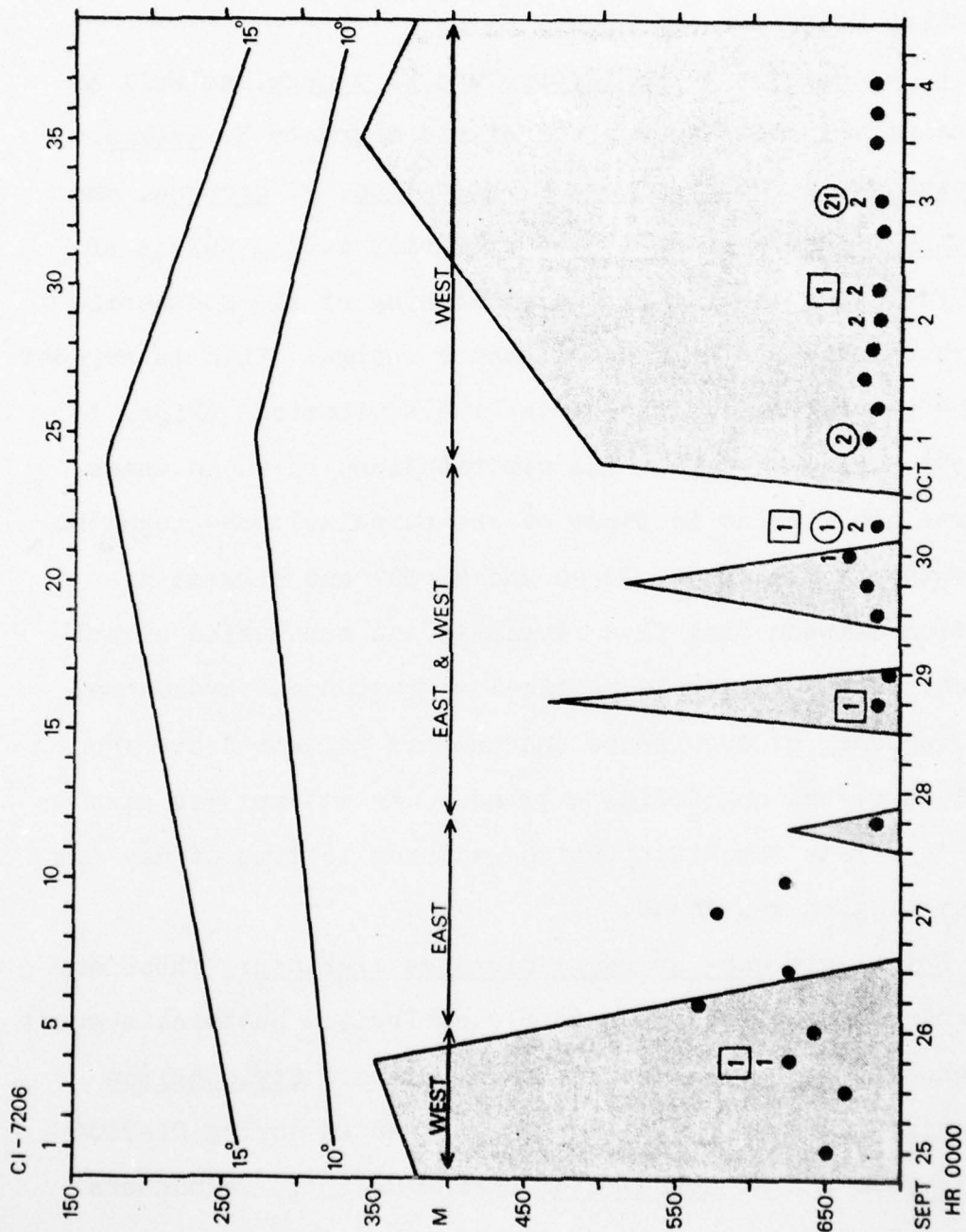
Figure 55

The occurrence of the epipelagic migrant species *Euphausia americana*, *E. hemigibba* (□), and *E. tenera* (○) in relation to changes in u, v, and t during CI-7206.
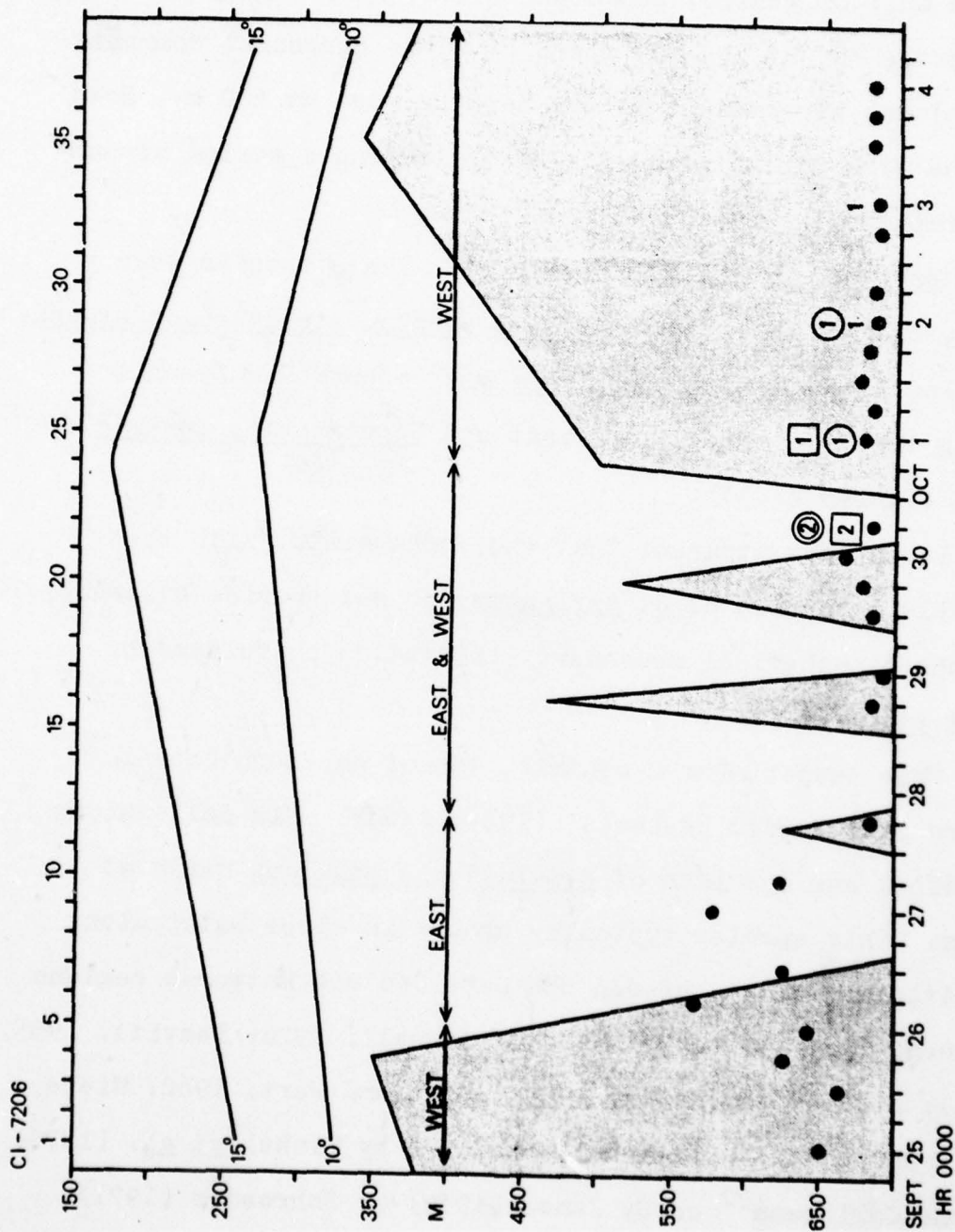
Figure 56

The occurrence of the epipelagic migrant species Euphausia mutica, E. pseudogibba (O), Nematoscelis atlantica (□), and N. microps (⊙) in relation to changes in u, v, and t during CI-7206.

usually found only in the upper 400 m, has been collected
from lower depths in areas adjacent to the Florida Straits.
In the Gulf of Mexico, Schroeder (1971) found maximum numbers
during the day at 390-479 m and P. Wiebe (personal communi-
cation) has reported it in the Sargasso Sea at 600 m. Both
species were collected during SWF following a period of sub-
geostrophy (Fig. 57).

Meso- and bathypelagic species: These species were
rarely collected. Nematobrachion boopis, Stylocheiron elonga-
tum, and Bentheuphausia amblyops each occurred only once
during the four sampling periods and Nematoscelis tenella
twice (Tables 27-30).

It is thus apparent that the euphausiids, with the
possible exception of S. carinatum, do not provide evidence
for the hypothetical secondary circulation postulated by
Düing et al. (1977).

Some support for a contribution of northern oceanic
waters is provided by Lewis' (1954) study. His collections
contained one specimen of Nematoscelis megalops taken at
494 m. This species typically occurs in slope water along
the Atlantic coast between the Cape Cod and Hatteras regions
(Hansen, 1915; Bigelow, 1922; Tattersall, 1926; Leavitt, 1935,
1938); Bigelow and Sears, 1939; Grice and Hart, 1962; Wiebe
and Boyd, 1978). It was not reported by Michel et al. (1976)
in the Caribbean[32] or by James (1970) or Schroeder (1971)

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[32]Records of N. megalops in Michel et al. (1976) are erro-
neous. The specimens thought to be N. megalops have since
been identified as N. microps/atlantica (H. Michel, personal
communication).

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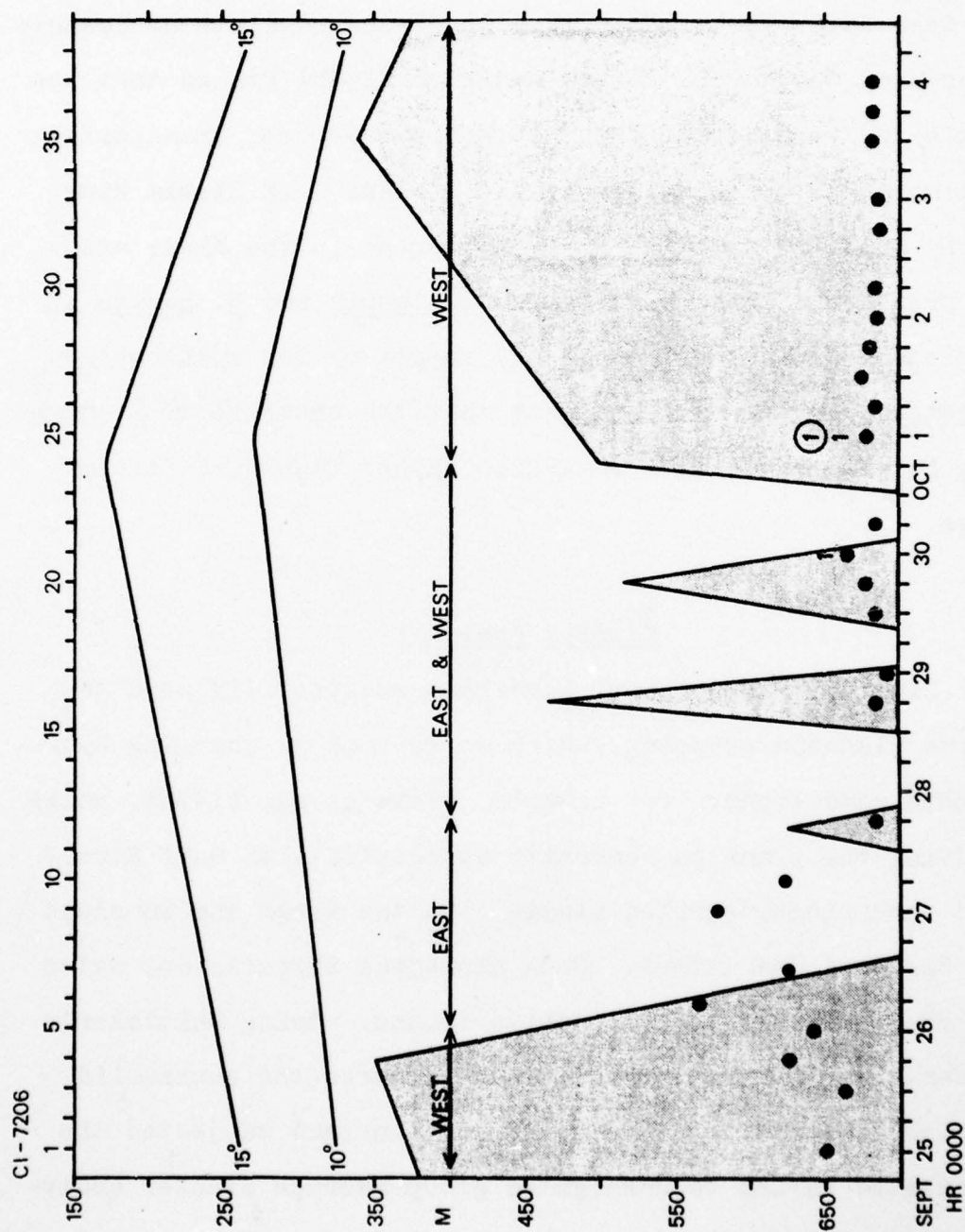
Figure 57

The occurrence of the epipelagic non- or short distance
migrant species *Stylocheiron abbreviatum* and *S. carinatum*
(○) in relation to changes in u, v, and t during CI-7206.

in the Gulf of Mexico. Owre and Foyo (1972) collected one
specimen in the Yucatan Channel. Lewis' report of N. megalops
at 494 m in the Florida Straits may be evidence that part of
the deep water involved in flow reversals consists of oceanic
water from the north. Wiebe and Boyd (1978) stated that the
single specimen reported by Lewis may have been transported
from northern slope waters by a cold core Gulf Stream ring
which coalesced with the Florida Current in the Miami area.
The presence of the chaetognaths S. tenuis and E. hamata in
this study and Wormelle's (1962) report of the euthecosome
L. retroversa, however, suggest that the presence of N. mega-
lops is related to flow reversals rather than Gulf Stream
rings.

Cluster Analysis

Clustering techniques have been successfully used to
define plankton groupings which correspond to changing hydro-
graphic conditions. For example, Wiebe et al. (1976), while
studying the plankton community associated with Gulf Stream
cold core rings, sampled stations in the rings and in slope
and Sargasso Sea waters. Both slope and Sargasso Sea water
are characterized by distinctive faunas. Using Whittaker's
percentage similarity index, they compared the euphausiid
species composition of pairs of stations and subjected the
calculated values to unweighted group average cluster analy-
sis. Two groups could be distinguished, one of slope and
ring stations in which characteristic slope water euphausiids

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were dominant, and the other of Sargasso Sea and ring stations in which characteristic Sargasso Sea euphausiids were dominant.

An attempt was made to structure the mixed aggregations in this study by grouping samples on the basis of species similarity. The similarity indices and clustering methods used (see METHODS), however, did not provide any new insights into the relation of the deep distribution of chaetognaths, euthecosomes, and euphausiids to changes in vertical structure of the Florida Current. For example, a cluster analysis plot of Whittaker's per cent similarity index values (Fig. 58) shows species composition affinities between stations for chaetognaths collected during CI-7206. Three clusters, representing groups of stations in which either epipelagic, meso-bathypelagic, or a combination of epi- and meso-bathypelagic species are numerically dominant (Table 9), are apparent. The associations, however, do not correspond to changes in vertical structure which occurred during CI-7206 (Figs. 9-12). A general lack of correspondence between groupings and physical conditions is also apparent in cluster analysis plots for the other data sets. This is due primarily to the nature of the physical changes associated with deep flow reversals. Epipelagic species are advected downward to depths of 500-600 m where they mix with the deep water fauna normally found at this level. Deep flow reversals occur every 4 or 5 days, resulting in a mixed fauna which is alternately carried to the northeast and southwest. Although

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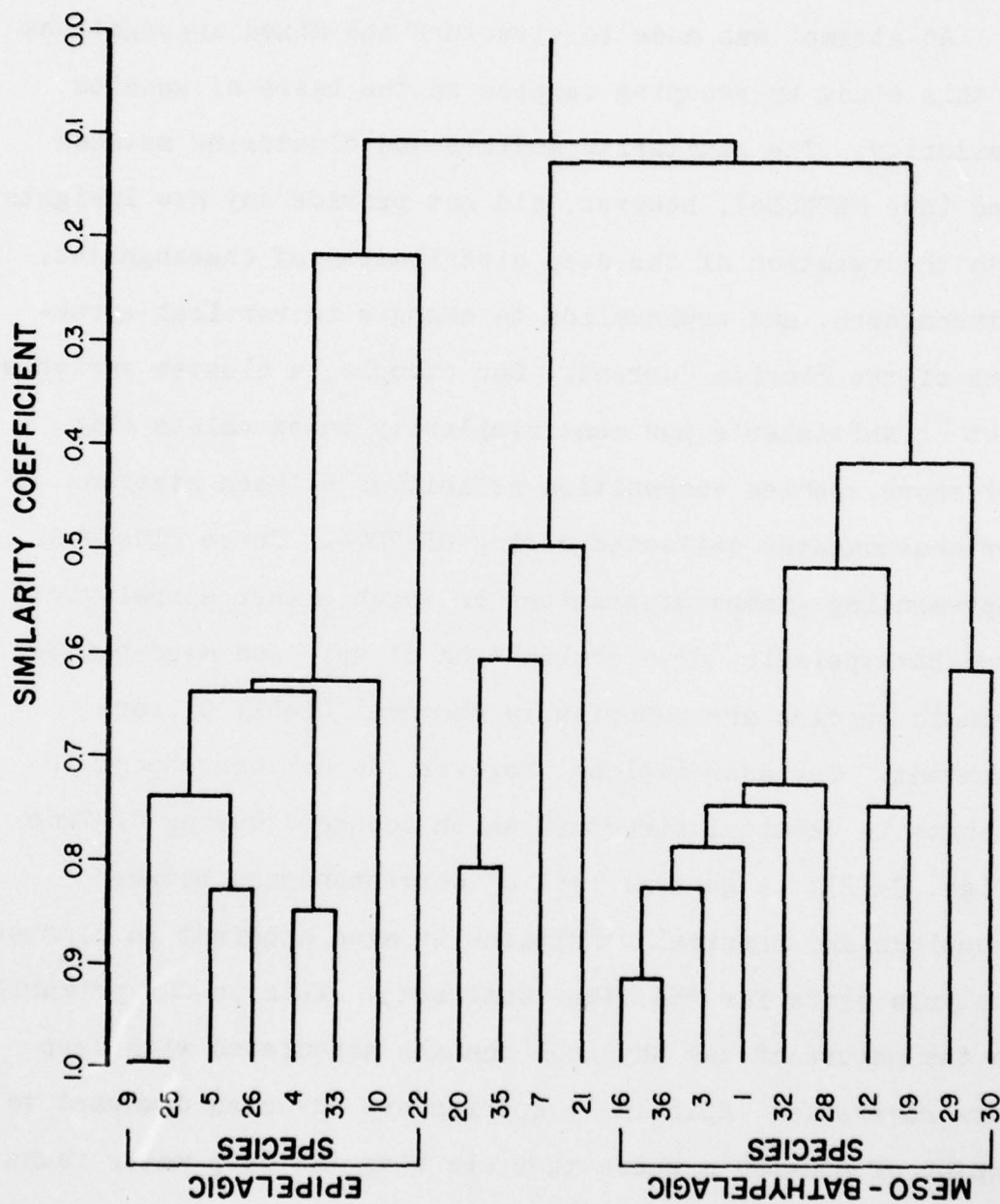
Cluster analysis plot of Whittaker's per cent similarity index values showing species composition affinities between stations for chaetognaths collected during CI-7205.

Figure 58

there is a greater possibility that larger numbers of indi-
vidual epipelagic species or rare species will occur imme-
diately following the subgeostrophic regime, representatives
of a given species could be present at the sampling point at
any time (Figs. 37 and 47). Thus, on the basis of species
composition, one station might be similar to another even
though the physical regime was totally different during each
collection (Fig. 58). The technique would be more useful in
an expanded study of deep flow reversals such as that dis-
cussed in the following section.

Although providing no new information on deep flow re-
versals, the calculations supported the rationale outlined
in the METHODS section for using both Sørensen's and
Whittaker's indices. In addition, the data indicated that
group average cluster analysis provides more information than
the single linkage method despite evidence that the latter is
mathematically superior to the former (Jardine and Sibson,
1971).

DISCUSSION

In this study, the role of chaetognath, euthecosome, and euphausiid species as indicators of the circulation and origin of waters associated with deep flow reversals in the Florida Straits is discussed. The unusual combinations of epipelagic neritic and oceanic species with meso- and bathy-pelagic forms below 600 m provided evidence for the hypothetical subgeostrophic condition postulated by Düing et al. (1977), i.e., downward movement of shallow water along the lower edge of the thermal front roughly defined by the 10°C and 15°C isotherms by a positive u-component during NWF. In addition, the presence of certain species suggests that the deep water in the Straits consists of a mixture of coastal, shallow oceanic, and deep oceanic waters from both local and northern regions. These results, summarized in Table 32 and discussed in detail in the previous sections on Deep Flow Reversals, Chaetognatha, Euthecosomata, and Euphausiacea, demonstrate the value of zooplankton species as indicators in interpreting physical measurements of oceanic phenomena.

Although all three groups contributed to a further understanding of vertical structure, the chaetognaths proved most useful, followed by the euthecosomes and the euphausiids (Table 32). The co-occurrences at 600 m of epipelagic chaetognaths, such as Krohnitta pacifica, Pterosagitta draco, Sagitta bipunctata, S. enflata, and S. serratodentata with the deep-living forms Eukrohnia bathyantarctica, E. bathy-

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Table 32

Summary of information on deep flow reversals provided by the distribution patterns of the Chaetognatha, Euthecosomata, and Euphausiacea collected in this study.

| | Downwelling of shallower water | Origin | | | | |
| | | Local | | Northern | | |
		Coastal	Oceanic Shallow	Coastal	Oceanic Shallow	Deep
Chaetognatha	+	+	+	+	-	+
Euthecosomata	+	-	+	-	+33	-
Euphausiacea	+(?)	-	-	-	+34	+34

33Based on Wormelle's (1962) report of _Limacina retroversa_.

34Based on Lewis' (1954) report of _Nematoscelis megalops_.

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pelagic, <u>E</u>. <u>fowleri</u>, <u>E</u>. <u>hamata</u>, and <u>Sagitta macrocephala</u>, provide evidence for downgliding along the lower edge of the thermal front during NWF. The presence of epipelagic eutheco- somes at 600 m, especially the non- or feebly migratory species <u>Cavolinia longirostris</u>, <u>Creseis acicula</u>, <u>C</u>. <u>virgula</u>, and <u>Limacina trochiformis</u> and the non- or short distance migrant species of euphausiid <u>Stylocheiron carinatum</u> also support this theory. The relative proportions of the chaeto- gnaths in the deep samples and the presence of such species as <u>Eukrohnia hamata</u>, <u>Sagitta helenae</u>, <u>S</u>. <u>hispida</u>, <u>S</u>. <u>tenuis</u>, and <u>S</u>. <u>megalopthalma</u> indicate local and northern contributions of coastal, shallow oceanic, and deep oceanic waters to the deep current. The epipelagic euthecosomes are indicators of shallow oceanic waters from either local or adjacent areas. Historical data on the euthecosomes and euphausiids point to a contribution from shallow (<u>Limacina retroversa</u>)and shallow or deep (<u>Nematoscelis megalops</u>) oceanic areas to the north.

These results show that the choice of zooplankton "indicator" organisms should depend on the nature of the physical processes to be studied. In examining horizontal phenomena, any organism or group of organisms which meet the criteria for the selection of indicator species, discussed in the INTRODUCTION, may be used. However, in studying vertical processes, particularly small-scale phenomena as downwelling, it is necessary to select a group whose species not only meet these criteria but also are restricted to relatively discrete strata. If the chaetognaths in the deep

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samples had not been identified, major evidence supporting Düing et al.'s (1977) hypothetical secondary circulation would have been overlooked.

Recommendations for Future Work

Although the results of this study support Düing et al.'s subgeostrophic condition, the 3- to 10-day sampling periods were too short (W. Düing, personal communication) and the numbers of animals collected too small to establish its existence with certainty. Since the dynamics of the Florida Current in the Straits off Miami are extremely complex, the proposed secondary circulation is probably not the only mechanism for advecting epipelagic species downwards. It is likely that it operates in combination with larger scale upwelling and downwelling associated with the reversal-generating continental shelf waves. Additional, more intensive biological sampling over a longer period is needed to elucidate the mechanisms of downward movement of epipelagic species and to evaluate the possibility, indicated by certain species, that part of the water in the deep current originates in areas to the north. Such a program would involve the collection of discrete zooplankton samples in the region of the 10°C and 15°C isotherms as well as near bottom, permitting examination of both the sub- and supergeostrophic regimes. Ideally, sampling would be conducted synoptically at two stations, one in the same area as the present study and a second on the Miami Terrace. The sampling period would be extended to at

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least 14 days, the duration of biological sampling lengthened,
and the anchored station occupied in summer and winter.

1·0

2·8   2·5

5·0   3·15   2·2

5·6
6·3   3·5   2·0

1·1   7·1   4·0

4·5   1·8

1·25   1·4   1·6
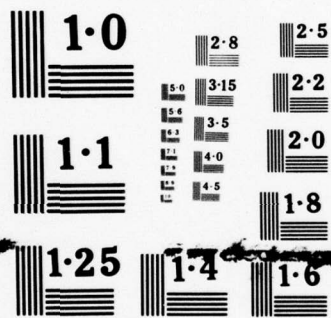
NATIONAL BUREAU OF STANDARDS
MICROCOPY RESOLUTION TEST CHART

CONCLUSIONS

1. Four sets of current profiles from an anchored station in the Florida Current off Miami show variations in the deep current similar to those found by previous investigators. Deep flow reversals of varying intensity occur at several-day intervals. When the v-component is directed toward the north, the u-component is easterly, and the thermal structure in the region of the 10°C - 15°C isotherms is flat and broad. When the v-component is oriented toward the south, cross-stream flow is westerly and the 10°C - 15°C isotherms are noticeably steepened.

2. Fluctuations in the deep thermal field in the Florida Straits off Miami appear to be related to both wind speed and direction.

3. Twenty species of Chaetognatha, fourteen species, one subspecies, and nine formae of Euthecosomata, and fifteen species of Euphausiacea were identified in samples collected below 600 m. Five of the chaetognaths, _Eukrohnia_ _bathyantarctica_, _E. bathypelagica_, _Sagitta_ _megalopthalma_, _S._ _tenuis_, and _S._ _zetesios_, and three euphausiids, _Bentheuphausia_ _amblyops_, _Euphausia_ _pseudogibba_, and _Thysanopoda_ _obtusifrons_, are new records for the Straits off Miami.

4. The occurrence of unusual combinations of epipelagic neritic and oceanic chaetognaths with meso- and meso-bathypelagic forms and the presence of many species of euthecosomes at 600 m during pulses of deep southwestward flow indicate

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downward movement of shallow oceanic waters. These data, as well as previous studies on the vertical distribution of chaetognaths and euthecosomes in the Straits, support the hypothetical subgeostrophic condition thought to occur in the Florida Current, i.e., downwelling along the lower edge of the thermal front roughly defined by the 10°C and 15°C isotherms by a positive u-component during northward flow. The animals occur in the following pulse of southward flow due to a lag between the time they are advected downward and the time they reach the sampling depth.

5. The similarity between the proportions of oceanic epipelagic chaetognath and euthecosome species in the deep samples and the known relative abundances of the same species in the Straits off Miami may indicate that part of the water advected downward is of local origin.

6. Certain species of chaetognaths collected in pulses of southward flow suggest that part of the deep water originates in coastal (<u>Sagitta</u> <u>tenuis</u>) and deep oceanic (<u>Eukrohnia</u> <u>hamata</u>) areas to the north. Historical data on the distribution of euthecosomes and euphausiids in the Florida Straits also point to a northern contribution of shallow (<u>Limacina</u> <u>retroversa</u>)and shallow or deep (<u>Nematoscelis</u> <u>megalops</u>) oceanic waters to the deep current.

7. Additional, more extensive biological sampling over a longer period of time is needed to confirm the results of this study and to provide further insights into the mechanisms for downward advection of epipelagic species in the Florida Current off Miami.

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APPENDIX I

Station data for CI-7206, CI-7309, CI-7317, and CI-7401.

Table 1

Anchored Station CI-7206
25°39'N 79°50'W

Station	Date (1972)	Time (EDT)	Fishing Depth* (m)	Volume Filtered* (m³)
1	25 Sept	0000-0310	650	860.99
2	25 Sept	0530-0826	-	-
3	25 Sept	1130-1445	665	115.71
4	25 Sept	1730-2050	627	1535.45
5	25/26 Sept	2300-0215	643	767.57
6	26 Sept	0515-0810	563	139.28
7	26 Sept	1100-1400	626	925.84
8	26 Sept	1730-2040	-	-
9	26/27 Sept	2300-0200	588	707.27
10	27 Sept	0500-0830	624	369.11
11	27 Sept	1115-1440	-	-
12	27 Sept	1615-2000	683	42.13
13	27/28 Sept	2250-0225	-	-
14	28 Sept	0600-1000	-	-
15	Missed station			
16	28 Sept	1630-2045	683	829.66
17	28/29 Sept	2230-0220	691	736.79
18	29 Sept	0515-0836	-	-
19	29 Sept	1100-1415	681	767.48
20	29 Sept	1700-2020	679	690.29
21	29/30 Sept	2300-0205	665	973.21
22	30 Sept	0500-0810	681	1275.99
23	30 Sept	1100-1425	-	-
24	30 Sept	1700-2050	-	-
25	30 Sept/1 Oct	2300-0230	679	1349.28
26	1 Oct	0500-0825	681	631.52
27	1 Oct	1100-1420	676	1246.40
28	1 Oct	1700-2025	680	1188.09
29	1/2 Oct	2300-0225	685	1427.98
30	2 Oct	0500-0830	685	1164.37
31	2 Oct	1100-1440	-	-
32	2 Oct	1700-2110	687	1786.26
33	2/3 Oct	2300-0220	685	1330.33
34	3 Oct	0500-0840	-	-
35	3 Oct	1100-1430	681	1073.52
36	3 Oct	1645-2020	681	1612.54
37	3/4 Oct	2300-0220	682	1382.36
38	4 Oct	0500-0830	-	-

*Missing data represent equipment malfunctions.

Table 2

Anchored Station CI-7309
25°38'N 79°49'W

Station	Date (1973)	Time (EDT)	Fishing Depth* (m)	Volume Filtered* (m³)
1	22 May	1115-1530	-	-
2	22 May	1730-2030	-	-
3	22 May	2030-2300	-	-
4	22/23 May	2330-0230	-	-
5	23 May	0600-0845	-	-
6	23 May	1115-1400	-	-
7	23 May	1400-1700	-	-
8	23 May	1730-2015	-	-
9	23/24 May	2315-0200	-	-
10	24 May	0530-0945	676	436.60
11	24 May	1130-1430	674	609.35
12	24 May	1730-2030	670	529.71
13	24/25 May	2315-0300	670	51S.36
14	25 May	0530-0845	670	492.42
15	25 May	1115-1415	671	411.09

*Missing data represent equipment malfunctions.

Table 3

Anchored Station CI-7317
25°38'N 79°49'W

Station	Date (1973)	Time (EDT)	Fishing Depth* (m)	Volume Filtered* (m³)
1	5 Oct	1700-2100	780	853.72
2	5/6 Oct	2300-0300	761	947.05
3	6 Oct	0515-0900	731	690.02
4	6 Oct	1115-1600	751	703.88
5	6 Oct	1730-2115	749	470.70
6	6/7 Oct	2315-0240	745	777.10
7	7 Oct	0530-0840	-	-
8	7 Oct	1130-1445	-	-
9	7 Oct	1730-2100	625	2313.01
10	7/8 Oct	2315-0130	636	1488.07
11	8 Oct	0530-0900	722	1267.25
12	8 Oct	1115-1430	725	849.58

*Missing data represent equipment malfunctions.

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Table 4

Anchored Station CI-7401
25°39'N 79°51'W

Station	Date (1974)	Time (EDT)	Fishing Depth* (m)	Volume Filtered* (m³)
1	19 Jan	1700-2030	610	694.72
2	19/20 Jan	2315-0245	-	-
3	20 Jan	0515-0830	633	740.08
4	20 Jan	1115-1400	-	-
5	20 Jan	1700-2030	608	675.42
6	20/21 Jan	2315-0215	608	874.66
7	21 Jan	0515-0830	586	633.25
8	21 Jan	1100-1430	612	437.00
9	21 Jan	1715-2030	610	437.48
10	21/22 Jan	2315-0230	-	-
11	22 Jan	0545-0845	-	-
12	22 Jan	1115-1420	629	381.02
13	22 Jan	1715-2030	629	408.33
14	22/23 Jan	2315-0220	634	504.65
15	23 Jan	0515-0830	-	-
16	23 Jan	1115-1415	625	538.64
17	23 Jan	1715-2100	-	-
18	23/24 Jan	2315-0300	620	500.70
19	24 Jan	0515-0830	595	631.55
20	24 Jan	1115-1430	635	594.56
21	24 Jan	1715-2030	610	707.20
22	24/25 Jan	2315-0220	-	-

*Missing data represent equipment malfunctions.

APPENDIX II

Distribution of individual species of Chaetognatha,
Euthecosomata, and Euphausiacea during CI-7206,
CI-7309, CI-7317, and CI-7401.

Chaetognatha

Table 1

Distribution of *Eukrohnia bathyantarctica*.

Cruise	Station	Depth (m)	No. per 1000 m^3	Per cent no. per 1000 m^3
CI-7206	16 28	683 680	1 2	5.0 5.9

Table 2

Distribution of *Eukrohnia bathypelagica*.

Cruise	Station	Depth (m)	No. per 1000 m^3	Per cent no. per 1000 m^3
CI-7206	36	681	1	5.3
CI-7317	5 9 12	749 625 725	2 1 1	6.9 6.0 10.0
CI-7401	16	625	4	20.0

Table 3

Distribution of *Eukrohnia fowleri*.

Cruise	Station	Depth (m)	No. per 1000 m^3	Per cent no. per 1000 m^3
CI-7206	1 3 4	650 665 627	1 8 2	25.0 33.3 6.5

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Table 3
(continued)

Cruise	Station	Depth (m)	No. per 1000 m^3	Per cent no. per 1000 m^3
	16	683	7	35.0
	28	680	14	41.2
	29	685	2	33.3
	30	685	5	35.7
	32	687	1	25.0
	36	681	6	31.6
CI-7309	10	676	2	25.0
	12	670	2	33.3
	13	670	4	15.4
	14	670	8	28.6
	15	671	5	15.2
CI-7317	5	749	4	13.8
	9	625	3	17.9
	10	636	1	14.3
	11	722	2	33.3
	12	725	4	40.0
CI-7401	1	610	4	33.3
	5	608	4	16.7
	6	608	7	36.8
	8	612	2	25.0
	12	629	10	52.6
	13	629	2	100.0
	16	625	4	20.0
	20	635	2	50.0

Table 4

Distribution of Eukrohnia hamata.

Cruise	Station	Depth (m)	No. per 1000 m^3	Per cent no. per 1000 m^3
CI-7206	3	665	2	8.3
CI-7309	13	670	2	7.7
	14	670	2	7.1

Table 4
(continued)

Cruise	Station	Depth (m)	No. per 1000 m^3	Per cent no. per 1000 m^3
CI-7317	3	731	1	2.3
	5	749	2	6.9
	9	625	5	29.8
	10	636	1	14.3
	12	725	1	10.0
CI-7401	16	625	4	20.0

Table 5

Distribution of Krohnitta pacifica.

Cruise	Station	Depth (m)	No. per 1000 m^3	Per cent no. per 1000 m^3
CI-7206	21	665	1	25.0

Table 6

Distribution of Krohnitta subtilis.

Cruise	Station	Depth (m)	No. per 1000 m^3	Per cent no. per 1000 m^3
CI-7206	10	624	3	37.5
CI-7309	13	670	2	7.7
CI-7317	3	731	7	15.9
CI-7401	6	608	3	15.8
	8	612	2	25.0

Table 7

Distribution of _Pterosagitta draco_.

Cruise	Station	Depth (m)	No. per 1000 m^3	Per cent no. per 1000 m^3
CI-7206	30	685	1	7.1
CI-7317	9	625	0.4	2.4

Table 8

Distribution of _Sagitta_ sp.[*]

Cruise	Station	Depth (m)	No. per 1000 m^3	Per cent no. per 1000 m^3
CI-7401	8	612	2	25.0
	18	620	2	11.1

[*]Small unidentifiable specimens of _Sagitta_.

Table 9

Distribution of _Sagitta bipunctata_.

Cruise	Station	Depth (m)	No. per 1000 m^3	Per cent no. per 1000 m^3
CI-7206	4	627	1	3.2
	20	679	1	3.1
	33	685	5	6.9
CI-7309	13	670	2	7.7
CI-7401	8	612	2	25.0

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Table 10

Distribution of *Sagitta decipiens*.

Cruise	Station	Depth (m)	No. per 1000 m^3	Per cent no. per 1000 m^3
CI-7206	3	665	2	8.3
	4	627	1	3.2
	22	681	1	14.3
	28	680	1	2.9
	33	685	4	5.6
CI-7317	3	731	10	22.7

Table 11

Distribution of *Sagitta enflata*.

Cruise	Station	Depth (m)	No. per 1000 m^3	Per cent no. per 1000 m^3
CI-7206	4	627	5	16.1
	7	626	6	54.5
	20	679	26	81.2
	21	665	2	50.0
	28	680	2	5.9
	29	685	1	16.7
	30	685	2	14.3
	33	685	18	25.0
	35	681	3	100.0
CI-7309	10	676	2	25.0
	11	674	3	42.9
	12	670	2	33.3
	13	670	4	15.4
	14	670	2	7.1
	15	671	7	21.2
CI-7317	1	780	2	100.0
	3	731	7	15.9
	4	751	3	100.0
	6	745	5	100.0
	9	625	0.4	2.4
	11	722	1	16.7
	12	725	2	20.0

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Table 11
(continued)

Cruise	Station	Depth (m)	No. per 1000 m^3	Per cent no. per 1000 m^3
CI-7401	1	610	1	8.3
	3	633	3	75.0
	5	608	6	25.0
	6	608	5	26.3
	7	586	2	100.0
	9	610	5	71.4
	12	629	3	15.8
	18	620	16	88.9
	19	595	3	100.0

Table 12

Distribution of _Sagitta_ _helenae_.

Cruise	Station	Depth (m)	No. per 1000 m^3	Per cent no. per 1000 m^3
CI-7206	20	679	1	3.1

Table 13

Distribution of _Sagitta_ _hexaptera_.

Cruise	Station	Depth (m)	No. per 1000 m^3	Per cent no. per 1000 m^3
CI-7206	4	627	1	3.2
	5	643	1	20.0
	7	626	2	18.2
	12	683	3	50.0
	19	681	1	25.0
	22	681	2	28.6
	26	681	2	16.7

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Table 13
(continued)

Cruise	Station	Depth (m)	No. per 1000 m^3	Per cent no. per 1000 m^3
	30	685	2	14.3
	33	685	2	2.8
CI-7309	15	671	2	6.1
CI-7317	3	731	1	2.3
	5	749	2	6.9
	10	636	1	14.3
CI-7401	3	633	1	25.0
	5	608	6	25.0
	16	625	2	10.0

Table 14

Distribution of _Sagitta hispida_.

Cruise	Station	Depth (m)	No. per 1000 m^3	Per cent no. per 1000 m^3
CI-7206	22	681	1	14.3
	30	685	2	14.3

Table 15

Distribution of _Sagitta lyra_.

Cruise	Station	Depth (m)	No. per 1000 m^3	Per cent no. per 1000 m^3
CI-7206	22	681	2	28.6
	28	680	1	2.9

Table 15
(continued)

Cruise	Station	Depth (m)	No. per 1000 m^3	Per cent no. per 1000 m^3
CI-7309	10	676	2	25.0
	14	670	2	7.1
CI-7317	5	749	2	6.9
	9	625	1	6.0
CI-7401	12	629	3	15.8

Table 16

Distribution of _Sagitta_ _macrocephala_.

Cruise	Station	Depth (m)	No. per 1000 m^3	Per cent no. per 1000 m^3
CI-7206	1	650	3	75.0
	3	665	12	50.0
	4	627	1	3.2
	7	626	2	18.2
	12	683	3	50.0
	16	683	11	55.0
	19	681	3	75.0
	20	679	4	12.5
	26	681	2	16.7
	28	680	14	41.2
	29	685	1	16.7
	30	685	2	14.3
	32	687	2	50.0
	36	681	11	57.9
CI-7309	11	674	2	28.6
	13	670	4	15.4
	14	670	10	35.7
	15	671	15	45.5
CI-7317	2	761	1	50.0
	3	731	3	6.8
	5	749	15	51.7
	9	625	6	35.7

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Table 16
(continued)

Cruise	Station	Depth (m)	No. per 1000 m^3	Per cent no. per 1000 m^3
	10	636	4	57.1
	11	722	3	50.0
	12	725	2	20.0
CI-7401	1	610	7	58.3
	5	608	7	29.2
	6	608	2	10.5
	12	629	3	15.8
	16	625	6	30.0
	20	635	2	50.0

Table 17

Distribution of _Sagitta megalopthalma_.

Cruise	Station	Depth (m)	No. per 1000 m^3	Per cent no. per 1000 m^3
CI-7206	21	665	1	25.0

Table 18

Distribution of _Sagitta minima_.

Cruise	Station	Depth (m)	No. per 1000 m^3	Per cent no. per 1000 m^3
CI-7309	15	671	2	6.1
CI-7317	3	731	1	2.3

Table 19

Distribution of _Sagitta_ _serratodentata_.

Cruise	Station	Depth (m)	No. per 1000 m^3	Per cent no. per 1000 m^3
CI-7206	4	627	20	64.5
	5	643	4	80.0
	7	626	1	9.1
	9	588	1	100.0
	10	624	5	62.5
	16	683	1	5.0
	22	681	1	14.3
	25	679	3	100.0
	26	681	8	66.7
	29	685	2	33.3
	33	685	43	59.7
	36	681	1	5.3
CI-7309	10	676	2	25.0
	11	674	2	28.6
	12	670	2	33.3
	13	670	8	30.8
	14	670	4	14.3
	15	671	2	6.1
CI-7317	2	761	1	50.0
	3	731	14	31.8
	5	749	2	6.9
CI-7401	5	608	1	4.2
	6	608	2	10.5
	9	610	2	28.6

Table 20

Distribution of _Sagitta_ _tenuis_.

Cruise	Station	Depth (m)	No. per 1000 m^3	Per cent no. per 1000 m^3
CI-7206	17	691	1	100.0

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Table 21

Distribution of _Sagitta zetesios_.

Cruise	Station	Depth (m)	No. per 1000 m³	Per cent no. per 1000 m³
CI-7206	32	687	1	25.0

Euthecosomata

Table 22

Distribution of _Cavolinia_ sp. *

Cruise	Station	Depth (m)	No. per 1000 m³ Adult	Juv	Total	Per cent no. per 1000 m³
CI-7401	6	608	-	1	1	1.7

*Following Haagensen (1976), all _Cavolinia_ juveniles smaller than 0.6-0.7 mm shell length were classified only as _Cavolinia_ sp.

Table 23

Distribution of _Cavolinia longirostris_ including _C. longirostris_ f. _longirostris_ and _C. longirostris_ f. _strangulata_.

Cruise	Station	Depth (m)	No. per 1000 m³ Adult	Juv	Total	Per cent no. per 1000 m³
CI-7206	21	665	-	1	1	10.0
	25	679	2	1	3	13.6
	30	685	2	-	2	66.7

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Table 23
(continued)

Cruise	Station	Depth (m)	No. per 1000 m^3			Per cent no. per 1000 m^3
			Adult	Juv	Total	
CI-7401	8	612	-	7	7	26.9
	18	620	6	-	6	15.8
	19	595	2	-	2	5.9

Table 24

Distribution of <u>Cavolinia</u> <u>longirostris</u> f. <u>longirostris</u>.

Cruise	Station	Depth (m)	No. per 1000 m^3			Per cent no. per 1000 m^3
			Adult	Juv	Total	
CI-7206	21	665	-	1	1	10.0
	25	679	2	1	3	13.6
	30	685	2	-	2	66.7
CI-7401	19	595	2	-	2	5.9

Table 25

Distribution of <u>Cavolinia</u> <u>longirostris</u> f. <u>strangulata</u>.

Cruise	Station	Depth (m)	No. per 1000 m^3			Per cent no. per 1000 m^3
			Adult	Juv	Total	
CI-7401	18	620	6	-	6	15.8

Table 26

Distribution of _Cavolinia tridentata_ f. _bermudensis_.

Cruise	Station	Depth (m)	No. per 1000 m^3 Adult	Juv	Total	Per cent no. per 1000 m^3
CI-7206	25	679	1	-	1	4.5

Table 27

Distribution of _Cavolinia uncinata_ f. _uncinata_.

Cruise	Station	Depth (m)	No. per 1000 m^3 Adult	Juv	Total	Per cent no. per 1000 m^3
CI-7206	21	665	1	-	1	10.0

Table 28

Distribution of _Clio pyramidata_ f. _lanceolata_.

Cruise	Station	Depth (m)	No. per 1000 m^3 Adult	Juv	Total	Per cent no. per 1000 m^3
CI-7206	4	627	-	1	1	12.5
	21	665	1	-	1	10.0
CI-7317	3	731	-	1	1	3.2

Table 29

Distribution of *Creseis* sp.[*]

Cruise	Station	Depth (m)	No. per 1000 m^3 Adult	Juv	Total	Per cent no. per 1000 m^3
CI-7206	17	691	–	1	1	33.3
	21	665	–	1	1	10.0
	29	685	–	1	1	12.5
	33	685	–	1	1	0.6
CI-7309	10	676	–	11	11	35.5
	11	674	–	8	8	57.1
	12	670	–	2	2	11.8
	13	670	–	14	14	14.6
CI-7317	4	751	–	1	1	50.0
	5	749	–	8	8	10.8
	12	725	–	1	1	33.3
CI-7401	9	610	–	2	2	0.3

[*]These are individuals of the genus *Creseis* whose lengths (<0.5 mm) were less than that of a complete embryonic shell and therefore could not be identified to species.

Table 30

Distribution of *Creseis* acicula including C. acicula f. acicula.

Cruise	Station	Depth (m)	No. per 1000 m^3 Adult	Juv	Total	Per cent no. per 1000 m^3
CI-7206	25	679	1	–	1	4.5
	28	680	–	2	2	18.1
	33	685	4	–	4	2.2
CI-7309	10	676	–	2	2	6.5
	11	674	2	–	2	14.3
	12	670	–	2	2	11.8
	13	670	–	10	10	10.4

Table 30
(continued)

Cruise	Station	Depth (m)	No. per 1000 m³ Adult	Juv	Total	Per cent no. per 1000 m³
CI-7317	2	761	1	4	5	62.5
	4	751	1	-	1	50.0
	5	749	-	6	6	8.1
	6	745	-	1	1	16.7
	12	725	1	-	1	33.3
CI-7401	13	629	-	2	2	0.3

Table 31

Distribution of Creseis acicula f. acicula.

Cruise	Station	Depth (m)	No. per 1000 m³ Adult	Juv	Total	Per cent no. per 1000 m³
CI-7206	25	679	1	-	1	4.5
	28	680	-	2	2	18.1
	33	685	4	-	4	2.2
CI-7309	10	676	-	2	2	6.5
	11	674	2	-	2	14.3
	12	670	-	2	2	11.8
	13	670	-	6	6	6.3
CI-7317	2	761	1	1	2	25.0
	5	749	-	6	6	8.1
	6	745	-	1	1	16.7
	12	725	1	-	1	33.3

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Table 32

Distribution of Creseis virgula including C. virgula f. conica
and C. virgula f. virgula.

Cruise	Station	Depth (m)	No. per 1000 m³			Per cent no. per 1000 m³
			Adult	Juv	Total	
CI-7206	10	624	-	3	3	27.3
	19	681	1	-	1	10.0
	29	685	1	-	1	12.5
	32	687	-	1	1	33.3
	33	685	-	4	4	2.2
CI-7309	10	676	-	11	11	35.5
	12	670	2	2	4	23.5
	13	670	-	35	35	36.5
	14	670	-	6	6	75.0
	15	671	-	5	5	50.0
CI-7317	3	731	1	-	1	3.2
	5	749	-	6	6	8.1
	9	625	0.4	-	0.4	25.0
CI-7401	8	612	-	2	2	7.7

Table 33

Distribution of Creseis virgula f. conica.

Cruise	Station	Depth (m)	No. per 1000 m³			Per cent no. per 1000 m³
			Adult	Juv	Total	
CI-7206	10	624	-	3	3	27.3
	19	681	1	-	1	10.0
	32	687	-	1	1	33.3
	33	685	-	1	1	0.6
CI-7309	10	676	-	2	2	6.5
	12	670	2	2	4	23.5
	15	671	-	2	2	22.2
CI-7317	3	731	1	-	1	3.2
	5	749	-	2	2	2.7
	9	625	0.4	-	0.4	25.0

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Table 34

Distribution of Creseis virgula f. virgula.

Cruise	Station	Depth (m)	No. per 1000 m³ Adult	Juv	Total	Per cent no. per 1000 m³
CI-7206	29	685	1	-	1	12.5
	33	685	-	3	3	1.7
CI-7401	8	612	-	2	2	7.7

Table 35

Distribution of Cuvierina columnella including C. columnella
f. atlantica.

Cruise	Station	Depth (m)	No. per 1000 m³ Adult	Juv	Total	Per cent no. per 1000 m³
CI-7206	21	665	1	-	1	10.0
	22	681	1	-	1	50.0
	25	679	1	-	1	4.5
	28	680	-	1	1	9.1
	33	685	-	2	2	1.1
CI-7401	6	608	1	1	2	3.4
	12	629	3	-	3	4.3
	18	620	6	2	8	21.1

Table 36

Distribution of Cuvierina columnella f. atlantica.

Cruise	Station	Depth (m)	No. per 1000 m³ Adult	Juv	Total	Per cent no. per 1000 m³
CI-7206	21	665	1	-	1	10.0
	22	681	1	-	1	50.0
	25	679	1	-	1	4.5

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Table 36
(continued)

Cruise	Station	Depth (m)	No. per 1000 m^3			Per cent no. per 1000 m^3
			Adult	Juv	Total	
CI-7401	12	629	3	-	3	4.3
	18	620	6	-	6	15.8

Table 37

Distribution of <u>Diacria</u> <u>trispinosa</u>.

Cruise	Station	Depth (m)	No. per 1000 m^3			Per cent no. per 1000 m^3
			Adult	Juv	Total	
CI-7206	4	627	-	1	1	12.5
	22	681	-	1	1	50.0
	26	681	-	2	2	22.2
CI-7317	2	761	-	1	1	12.5
	3	731	-	1	1	3.2

Table 38

Distribution of <u>Diacria</u> <u>quadridentata</u>.

Cruise	Station	Depth (m)	No. per 1000 m^3			Per cent no. per 1000 m^3
			Adult	Juv	Total	
CI-7309	14	670	-	2	2	25.0
CI-7317	2	761	-	1	1	12.5
CI-7401	8	612	-	2	2	7.7

Table 39

Distribution of *Limacina bulimoides*.

Cruise	Station	Depth (m)	No. per 1000 m³ Adult	Juv	Total	Per cent no. per 1000 m³
CI-7206	19	681	-	1	1	10.0
	26	681	2	-	2	22.2
	33	685	-	1	1	0.6

Table 40

Distribution of *Limacina inflata*.

Cruise	Station	Depth (m)	No. per 1000 m³ Adult	Juv	Total	Per cent no. per 1000 m³
CI-7206	4	627	1	1	1	12.5
	10	624	-	8	8	72.7
	17	691	-	1	1	33.3
	19	681	-	1	1	10.0
	21	665	-	2	2	20.0
	25	679	4	2	7	31.8
	28	680	-	2	2	18.1
	29	685	-	3	3	37.5
	32	687	1	2	2	66.7
	33	685	9	20	29	16.3
CI-7317	2	761	-	1	1	12.5
	3	731	12	13	25	80.6
CI-7401	9	610	-	2	2	0.3

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Table 41

Distribution of _Limacina_ _lesueuri_.

Cruise	Station	Depth (m)	No. per 1000 m^3			Per cent no. per 1000 m^3
			Adult	Juv	Total	
CI-7206	4	627	-	1	1	12.5
CI-7317	11	722	-	1	1	50.0
CI-7401	8	612	-	2	2	7.7

Table 42

Distribution of _Limacina_ _trochiformis_ including _L._ _bulimoides_ or _L._ _trochiformis_ juveniles.

Cruise	Station	Depth (m)	No. per 1000 m^3	Per cent no. per 1000 m^3
CI-7206	4	627	3	37.5
	12	683	6	100.0
	17	691	1	33.3
	19	681	7	70.0
	20	679	1	100.0
	21	665	3	30.0
	25	679	8	36.3
	26	681	5	55.6
	28	680	5	45.5
	29	685	3	37.5
	30	685	1	33.3
	33	685	129	72.5
	36	681	1	50.0
CI-7309	10	676	7	22.6
	11	674	2	14.3
	12	670	9	52.9
	13	670	37	38.5
	15	671	5	50.0
CI-7317	5	749	48	64.9
	6	745	5	83.3
	9	625	1.4	75.0
	11	722	1	50.0

Cruise	Station	Depth (m)	No. per 1000 m^3	Per cent no. per 1000 m^3
	12	725	1	33.3
CI-7401	1	610	39	100.0
	3	633	2	100.0
	5	608	22	95.6
	6	608	50	86.2
	7	586	3	50.0
	8	612	13	50.0
	9	610	738	99.5
	12	629	66	95.7
	13	629	590	99.6
	14	634	44	100.0
	16	625	11	100.0
	18	620	24	63.2
	19	595	30	88.2
	20	635	2	40.0
	21	610	1	100.0

Table 43

Distribution of _Limacina trochiformis_.

Cruise	Station	Depth (m)	No. per 1000 m^3			Per cent no. per 1000 m^3
			Adult	Juv	Total	
CI-7206	12	683	3	3	6	100.0
	17	691	1	-	1	33.3
	25	679	1	-	1	4.5
	28	680	1	-	1	9.1
	29	685	-	1	1	12.5
	33	685	-	3	3	1.7
CI-7317	5	749	4	4	8	10.8
	9	625	0.4	-	0.4	25.0
	12	725	-	1	1	33.3
CI-7401	3	633	1	-	1	50.0
	5	608	-	1	1	4.3
	6	608	1	1	2	3.4

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Table 43
(continued)

Cruise	Station	Depth (m)	No. per 1000 m³			Per cent no. per 1000 m³
			Adult	Juv	Total	
	8	612	-	2	2	7.7
	13	629	-	2	2	0.3
	16	625	-	4	4	36.4
	18	620	2	-	2	5.3
	19	595	-	3	3	8.8

Table 44

Distribution of <u>Limacina</u> <u>trochiformis</u> or <u>Limacina</u> <u>bulimoides</u> juveniles.*

Cruise	Station	Depth (m)	No. per 1000 m³	Per cent no. per 1000 m³
CI-7206	4	627	3	37.5
	19	681	7	70.0
	20	679	1	100.0
	21	665	3	30.0
	25	679	7	31.8
	26	681	5	55.6
	28	680	4	36.4
	29	685	2	25.0
	30	685	1	33.3
	33	685	126	70.8
	36	681	1	50.0
CI-7309	10	676	7	22.6
	11	674	2	14.3
	12	670	9	52.9
	13	670	37	38.5
	15	671	5	50.0
CI-7317	5	749	40	54.1
	6	745	5	83.3
	9	625	1	50.0
	11	722	1	50.0
CI-7401	1	610	39	100.0
	3	633	1	50.0

Table 44
(continued)

Cruise	Station	Depth (m)	No. per 1000 m^3	Per cent no. per 1000 m^3
	5	608	21	91.3
	6	608	48	82.8
	7	586	3	50.0
	8	612	11	42.3
	9	610	738	99.5
	12	629	66	95.7
	13	629	588	99.3
	14	634	44	100.0
	16	625	7	63.6
	18	620	22	57.9
	19	595	27	79.4
	20	635	2	40.0
	21	610	1	100.0

*For those individuals less than 0.7 mm in height, it was difficult to distinguish between L. bulimoides and L. trochiformis on a morphological basis. Following Haagensen (1976), the specimens were identified using known distribution patterns in the area. Wormelle (1962) records L. trochiformis as the second most abundant euthecosome in the Florida Straits and L. bulimoides as relatively rare (<1.0%). L. bulimoides or L. trochiformis juveniles were thus considered to be L. trochiformis and are included in Appendix II, Table 42.

Table 45

Distribution of Styliola subula.

Cruise	Station	Depth (m)	No. per 1000 m^3			Per cent no. per 1000 m^3
			Adult	Juv	Total	
CI-7206	4	627	1	-	1	12.5
	25	679	1	1	1	4.5
	28	680	1	-	1	9.1
	33	685	7	2	8	4.5
	36	681	-	1	1	50.0

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Table 45
(continued)

Cruise	Station	Depth (m)	No. per 1000 m^3			Per cent no. per 1000 m^3
			Adult	Juv	Total	
CI-7309	11	674	2	-	2	14.3
CI-7317	3	731	1	1	3	9.7
	5	749	-	2	2	2.7
CI-7401	5	608	-	1	1	4.3
	6	608	-	5	5	8.6
	19	595	-	2	2	5.9
	20	635	3	-	3	60.0

Table 46

Distribution of unknown euthecosome.

Cruise	Station	Depth (m)	No. per 1000 m^3	Per cent no. per 1000 m^3
CI-7317	5	749	4	5.4
CI-7401	7	586	3	50.0

Euphausiacea

Table 47

Distribution of Bentheuphausia amblyops.

Cruise	Station	Depth (m)	No. per 1000 m^3	Per cent no. per 1000 m^3
CI-7309	15	671	2	100.0

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Table 48

Distribution of _Euphausia_ sp.*

Cruise	Station	Depth (m)	No. per 1000 m^3	Per cent no. per 1000 m^3
CI-7317	3	731	4 ♀	8.2

*Unidentifiable specimens of _Euphausia_.

Table 49

Distribution of _Euphausia_ _americana_.

Cruise	Station	Depth (m)	No. per 1000 m^3	Per cent no. per 1000 m^3
CI-7206	4	627	1 ♀	25.0
	21	665	1 ♀	50.0
	22	681	2 ♀♂	22.2
	29	685	2 ♀♂	40.0
	30	685	2 ♀♂	50.0
	33	685	2 ♀♂	6.1
CI-7309	12	670	2 ♀	100.0
CI-7317	3	731	1 ♀	2.0
CI-7401	5	608	1 ♂	50.0
	6	608	1 ♀	25.0
	9	610	2 ♀	50.0

Table 50

Distribution of _Euphausia hemigibba_.

Cruise	Station	Depth (m)	No. per 1000 m^3	Per cent no. per 1000 m^3
CI-7206	4	627	1 ♂	25.0
	16	683	1 ♀	100.0
	22	681	1 ♂	11.1
	30	685	1 ♀	25.0
CI-7317	3	731	1 ♂	2.0
	9	625	0.4 ♀	50.0
CI-7401	18	620	6 ♀♂	50.0
	19	595	2 ♂	100.0
	20	635	2 ♂	22.2

Table 51

Distribution of _Euphausia mutica_.

Cruise	Station	Depth (m)	No. per 1000 m^3	Per cent no. per 1000 m^3
CI-7206	29	685	1 ♂	20.0
	33	685	1 ♂	3.0

Table 52

Distribution of _Euphausia pseudogibba_.

Cruise	Station	Depth (m)	No. per 1000 m^3	Per cent no. per 1000 m^3
CI-7206	25	679	1 ♀♂	16.7
	29	685	1 ♂	20.0

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Table 52
(continued)

Cruise	Station	Depth (m)	No. per 1000 m^3	Per cent no. per 1000 m^3
CI-7317	3	731	3 ♂	6.1

Table 53

Distribution of <u>Euphausia</u> <u>tenera</u>.

Cruise	Station	Depth (m)	No. per 1000 m^3	Per cent no. per 1000 m^3
CI-7206	22	681	1 ♀	11.1
	25	679	2 ♂	33.3
	33	685	21 ♀♂	63.6
CI-7317	3	731	13 ♀♂	26.5
CI-7401	6	608	1 ♀	25.0
	14	634	2 ♂	100.0
	20	635	2 ♂	22.2

Table 54

Distribution of <u>Nematobrachion</u> <u>boopis</u>.

Cruise	Station	Depth (m)	No. per 1000 m^3	Per cent no. per 1000 m^3
CI-7401	6	608	1 ♀	25.0

Table 55

Distribution of _Nematobrachion flexipes_.

Cruise	Station	Depth (m)	No. per 1000 m^3	Per cent no. per 1000 m^3
CI-7317	1	780	1 ♂	100.0

Table 56

Distribution of _Nematoscelis atlantica_.

Cruise	Station	Depth (m)	No. per 1000 m^3	Per cent no. per 1000 m^3
CI-7206	22	681	2 ♀	22.2
	25	679	1 ♀	16.7
CI-7317	3	731	1 ♀	2.0
	9	625	0.4 ♀	50.0

Table 57

Distribution of _Nematoscelis microps_.

Cruise	Station	Depth (m)	No. per 1000 m^3	Per cent no. per 1000 m^3
CI-7206	22	681	2 ♀♂	22.2
CI-7401	3	633	1 ♀	100.0
	6	608	1 ♀	25.0
	7	586	2 ♂	100.0
	18	620	4 ♀♂	33.3

Table 58

Distribution of *Nematoscelis tenella*.

Cruise	Station	Depth (m)	No. per 1000 m^3	Per cent no. per 1000 m^3
CI-7206	30	685	1 ♀	25.0
CI-7401	18	620	2 ♀	16.7

Table 59

Distribution of *Stylocheiron abbreviatum*.

Cruise	Station	Depth (m)	No. per 1000 m^3	Per cent no. per 1000 m^3
CI-7206	21	665	1 ♀	50.0
	25	679	1 ♀	16.7
CI-7317	12	725	1 ♀	100.0
CI-7401	16	625	2 ♀	50.0

Table 60

Distribution of *Stylocheiron carinatum*.

Cruise	Station	Depth (m)	No. per 1000 m^3	Per cent no. per 1000 m^3
CI-7206	25	679	1 ♀	16.7
CI-7401	5	608	1 ♂	50.0
	9	610	2 ♀	50.0

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Table 61

Distribution of _Stylocheiron elongatum_.

Cruise	Station	Depth (m)	No. per 1000 m^3	Per cent no. per 1000 m^3
CI-7206	22	681	1 ♂	11.1

Table 62

Distribution of _Thysanopoda obtusifrons_.

Cruise	Station	Depth (m)	No. per 1000 m^3	Per cent no. per 1000 m^3
CI-7317	3	731	1 ♀	2.0

Table 63

Distribution of immature euphausiids.

Cruise	Station	Depth (m)	No. per 1000 m^3	Per cent no. per 1000 m^3
CI-7206	4	627	2	50.0
	10	624	3	100.0
	28	680	1	100.0
	29	685	1	20.0
	32	687	1	100.0
	33	685	9	27.3
CI-7309	13	670	2	100.0
CI-7317	3	731	25	51.0
CI-7401	16	625	2	50.0
	20	635	5	55.6

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20.   Abstract

The occurrence of chaetognath, euthecosome, and euphausiid species in relation to deep flow reversals in the Florida Straits off Miami was examined during four, 3- to 10-day periods in 1972-1974.   Simultaneous zooplankton collections and current profiles were made at 6-hr intervals while anchored in 650-800 m at a station 15 miles east of Miami.   The sampling depth was 600-750 m and the duration of fishing 1-1½ hrs.

Time-depth contour plots of the u- and v-components of velocity and temperature show variations in the deep current similar to those found by previous investigators.   Deep flow reversals of varying intensity occurred at several-day intervals.   When the v-component was directed toward the north, the u-component was easterly, and the thermal structure, particularly in the region of the 10°C - 15°C isotherms, was flat and broad.   When the v-component was oriented toward the south, cross-stream flow was westerly, and the 10°C - 15°C isotherms were noticeably steepened.

Twenty species of Chaetognatha, 14 species, 1 subspecies, and 9 formae of Euthecosomata, and 15 species of Euphausiacea were identified in the deep samples.   The observed distribution patterns of these species were evaluated in terms of the known horizontal and vertical ranges of each species and compared with the simultaneously collected physical data.   Combinations of epipelagic neritic and oceanic chaetognath species with meso- and meso-bathypelagic forms and the presence of many euthecosome species during pulses of deep southwestward flow indicate a downward movement of shallow oceanic waters.   These data, as well as previous studies on the vertical distribution of chaetognaths and euthecosomes in the Straits, support the hypothetical subgeostrophic condition thought to occur in the Florida Current, i.e., downwelling along the lower edge of the thermal front roughly defined by the 10°-15°C isotherms by a positive u-component during northward flow. The relative proportions of epipelagic species found below 600 m and the presence of certain species, e.g., Sagitta tenuis and Eukrohnia hamata suggest that the deep water present in flow reversals consists of a mixture of coastal, shallow oceanic, and deep oceanic waters from both local and northern regions.